

A
SURVEY
OF
EXPERIMENTAL
PHILOSOPHY.

VOL. I.

3 U R V E Y

OF

EXPERIMENTAL

PHILIP



PHILIP

VOL. I

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A

S U R V E Y
OF
EXPERIMENTAL
PHILOSOPHY,

Considered in its
PRESENT STATE OF IMPROVEMENT.

ILLUSTRATED WITH CUTS.

IN TWO VOLUMES.

VOL. I.

By OLIVER GOLDSMITH, M. B.

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MDCCLXXVI.

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ERRATA.

P. 32, l. 7, for *Plate*, read *Figure*.

P. 37, l. 6 from the Bottom, for *Plate II*.

Fig. 3. read *Fig. 2.*

P. 40, l. 2, dele *Plate II*.

P. 136, last line, read *it*.

P. 153, l. 5 from Bottom, read *C, B*,



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THE first volume of this work was printed off in the life-time of the author; the second after his death, the whole of the copy being put into the hands of the publisher long before that period. The design of the author is evidently to give a short view of Experimental Philosophy in its present improved state; for which it is indebted principally to the philosophers of the last century, who have done more towards it, than had been attempted for whole ages before. The ancients, satisfied with the facts which nature spontaneously offered, went no farther than to a bare natural history, unacquainted as they

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were with the manner of combining natural bodies, so as from this combination to produce new phaenomena, and of putting them in such circumstances as to force them to reveal their secrets. Our author having observed, that *Descartes* raised this spirit of enquiry, and diffused an uncommon degree of emulation all over Europe, proceeds to consider matter, the common substratum of bodies, and its sensible qualities; such as solidity, by which one body cannot at the same time occupy the room of another, the consequence of the *vis inertiae* or power of resistance, called also impenetrability, and by which we distinguish matter from a thinking being,

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being, which is endued with a constant tendency to change spontaneously its state, the very reverse of inactivity. The moving force in bodies is equally with their inactivity a passive quality, and a consequence of their resistance, and therefore the same thing with it, only considered in a different view. Attraction, or the tendency of matter to matter, seems to be the effect of some unknown cause, rather than an inherent quality in matter; different species of which are magnetism and electricity: in which, that repulsion, which is observable, seems to be owing to a reciprocation of the motion of the cause of both these phenomena. To these

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these we may add gravity, the tendency of a body to the centre of another. From motion arises the divisibility of a body, which by means of art may be carried to great lengths.---To follow our author through the different branches of experimental philosophy, would carry us too far, and much exceed the limits of an advertisement. The reader will find his account in the perusal, and meet with some things new and uncommon, which are not unworthy the author, nor the attention of the Public.

ERRATA in VOL. I.

- In the Note p. 26, l. 3, *read* Mores: Trahitur.
 Ib. l. 4, *read* domitrixque.
 P. 152, l. 3, *read* Fig. 14.
 Ib. l. 7 from the Bottom, after F G H,
read Fig. 21.
 P. 153, l. 5 from the Bottom, *read* CD.
 P. 242, last line, *read* Fig. 12 and 34.
 P. 270, l. 3 from the Bottom, *read* Spokes,

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A SURVEY

A SURVEY

OF
EXPERIMENTAL
PHILOSOPHY.

IN order to explain all the appearances of Nature, the ancients usually considered man as a Being newly introduced into the world, ignorant of all he saw, and astonished with every object around him. In this great variety, the first efforts of such a Being would be to procure subsistence, and, careless of the causes of things, to rest contented with their enjoyment.

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THE next endeavour of such a creature would be to know by what means he became blest with such a luxuriance of possession. He feels the grateful vicissitudes of day and night, perceives the difference of seasons ; he finds some things noxious to his health, and others grateful to his appetite ; he would therefore eagerly desire to be informed how these things assumed such qualities, and would himself, from want of experience, form some wild conjecture concerning them. He would, for instance, assert, as the primæval ancients have done, that the sun was made of red-hot iron, that at night it sunk into the sea to rest from its journey, that summer issued through a chasm made in the skies for that purpose ; and in this manner he would account for every other appearance that excited his curiosity.

SUCCEEDING observations would, however, soon contradict his first prejudices, and he would begin to treasure up an history of the changes, that every object

object served to work either upon himself or upon each other. Thus his mind would become stored with the appearances of natural bodies, and with useful observations upon their effects. The number of these observations would in time arise to a considerable amount, and this would once more induce him to reduce them into form; and, by combining them, to arrive at their causes. From hence new systems would be erected, more plausible indeed than those already made by savage man, but still, from a want of a sufficient number of materials, extremely defective: so that fancy would be obliged to supply the greatest share of the fabric.

AT length, after frequently experiencing the futility of system, man would be obliged to acknowledge his ignorance of the causes of most appearances, and now, grown more modest, would set himself down, not only to collect new observations, in order to enlarge his history of Nature, but in a manner to

4 A SURVEY of

torture Nature by *Experiments*, and oblige her to give up those secrets, which she had hitherto kept concealed. Several of these newly-acquired observations being thus added to the former obvious amount, would at length form the ground-work of a system, and, by comparing each part, and uniting the whole, man would at last begin to discover the simplicity of Nature under all her seeming variety.

SUCH is the progress of natural philosophy in the human mind, which, from enjoyment, proceeds to *conjecture*; from thence to *observation of facts*, which from their paucity give birth to *hypothetical* system, which is succeeded by experimental investigation, and this at length gives rise to the true *Experimental* system, which, though still defective, is yet built upon the surest foundation.

EXPERIMENTAL philosophers therefore, or those who endeavour to discover the hidden operations of Nature, and find out new properties by trials made upon

upon her, are the only sect, from whom any expectations are to be had of advancing this science, and making us intimately acquainted with whatever we see. We should leave to the Platonists their properties of number and geometrical figures; to the Peripatetics their privations, elementary virtues, occult qualities, sympathies, antipathies, and faculties; to the Mechanists their matter, motion, subtile particles, and actions of effluvia, and only follow where Experience shall guide us.

THE ancients seem to have been but little acquainted with the arts of making experiments for the investigation of natural knowledge. It is true, they treasured up numberless observations, which Nature offered to their view, or which chance might have given them an opportunity of seeing; but they seldom went further than barely the natural history of every object: they seldom laboured, by variously combining natural bodies, if I may so express it, to create

new appearances, in order to afford matter for speculation.

THEY were but little employed in thus diving into the secret recesses of Nature: they read the book as it lay before them; but then they read with great assiduity. Many facts, which they have advanced, and which had at first been denied by the moderns, have been afterwards found to be true. They only sought for such qualities in Nature as might be useful to the arts. Little concerned as to satisfying mere curiosity, they considered it as an intellectual pleasure, and only sought to gratify it by mere intellectual speculations.

BUT whatever assistance they might have given to real philosophy, the obscure ages, which succeeded theirs, seemed not disposed to avail themselves of their researches. In these times of darkness, they rested perfectly satisfied with words instead of things, adopted the vain speculations of antiquity, and added many
more

more of their own. Yet, in the midst of this barbarous period, there arose a man, who seemed formed to enlighten his cotemporaries, if the darkness had not been too great for any single luminary to dispel. *Roger Bacon*, an *Englishman* and a monk of the twelfth century, pursued the true method of investigating Nature: he even ventured to ridicule the unmeaning philosophy of *Aristotle*, or rather of his commentators; made several experiments in optics, chemistry, and every part of natural knowledge, and, even at that early period, found out the use of gun-powder. The only recompence he had from his ignorant cotemporaries was to be accused of magic, and to have his works despised by such as never read them, or were incapable of comprehending them if they had.

THE remarkable men, who succeeded *Bacon* in the pursuit of natural knowledge, studied it rather as chemists than philosophers: they applied themselves to the analysation of particular bodies

by fire, and to their uses in medicine, rather than to consider Nature with a general view, to the discovery of the laws of her operations. Though they were rich in a variety of curious and useful discoveries, yet they knew nothing, for instance, of the laws of motion, or the properties of fluids, upon a knowledge of which the whole system of modern philosophy is founded.

THE great man, to whom experimental philosophy next owed its obligations, was of the same name and the same country with the former. *Francis Bacon*, lord *Verulam*, first discovered the general principles, which were to serve as guides in the study of Nature. He first proposed the usefulness of experiments alone, and hinted at several, which others afterwards made with success. He set out with taking a general survey of natural knowledge, divided it into its parts, enquired into the degree of perfection at that time attained by each. He considered philosophy as only

an instrument, which made us better or happier, and an enemy to all systems, exhorted men to study only what was useful. This great man having thus broke through many of the chains, in which true science was bound, was still deterred from attempting others, which prejudice and authority seemed to fasten.

IN this Review of Experimental Philosophy, *Des Cartes* must not be passed over, although mentioned rather for his fame than his services. He contributed not a little to explode the errors of scholastic philosophy; but, unfortunately, it was to substitute his own. Though he was very capable of reasoning closely, yet, to accommodate his philosophy to the multitude, he drew up rather a romance than a system. Like all works that strike the imagination, it pleased while new; but, wanting the basis of reason, the whole fabric has long since fallen to the ground. As his hypothesis, however, has been once embraced by the greatest part of *Europe*, and still continues

tinues to have its partisans, it may not be amiss to give the learner a superficial idea of it.

It is on all hands acknowledged, that the most obvious appearances in Nature are those which are least understood. Why, for instance, a stone, when thrown upward, should fall to the ground back again, and not continue to go up to the skies, is one of those difficulties, which, though disregarded by the vulgar, has puzzled the philosophers of every age. To express it more philosophically, the descent of bodies to the surface of the earth is a phenomenon long sought after without success, and for the cause of which *Des Cartes* thus attempted to account. We are certain from astronomical observations, says he, that the earth turns continually round upon itself, like a top, with a very rapid motion, carrying with it every thing immediately attached to its surface. But, tho' the earth thus moves with great swiftness, yet there is diffused around it a very

very subtle matter, which, as it has less weight than the earth, has therefore much greater velocity, the lightest bodies being the most easily moved: so that this subtil matter whirls round the earth infinitely faster than the earth itself can move. If therefore a stone is thrown from the earth's surface upward into this subtle matter, it must soon be prest downward by it to the earth again, in the same manner as if a person, in the midst of a whirlpool, should throw a plank from him into the surrounding current, this plank would be soon driven back to him in the center again by the circulating fluid, and he could never by such means get free. In this way every one of the planets may be considered with its vortex or whirlpool of subtil matter turning round it, and pressing all the bodies that are thrown upward back upon its surface. Besides these particular vortexes in which each moved, they were represented as having altogether one common vortex, which regulated their motions, and in this manner

manner all their revolutions were in the gross accounted for. An hypothesis thus formed by the fancy was liable to a thousand objections, which were drawn from experience. Each of these, the followers of *Des Cartes* endeavoured to answer, till at length the whole philosophical machine was found so much clogged, that it became utterly disregarded by its warmest asserters: they therefore quitted a fortress, which they found could be assailed on every side with advantage.

BUT, notwithstanding all his errors, he diffused a passion for natural knowledge, and excited a spirit of enquiry, which insensibly spread itself over *Europe*. The academy of *Cimento* at *Florence*, *Boyle*, *Mariotte*, *Torricelli*, *Huygens*, and *Pascal*, all improved philosophy by producing new objects of speculation. The societies of *London* and *Paris* still farther enlarged the land-marks of the science, and adopted the experimental methods of investigating Nature. Though they had

had not yet arrived at the true system of Nature, yet they might justly be said to be on the road.

At length *Newton* appeared, who first effected what his predecessors had hitherto only aimed at; namely, the application of geometry to Nature, and, by uniting experiments with mathematical calculations, discovered new laws of Nature, in a manner at once precise, profound, and amazing. Whatever all his predecessors, from time immemorial, had handed down concerning this science, does not amount to the tenth part of the discoveries of the *English* philosopher only. Equally conspicuous for his researches in optics, as for his system of the world, he had the pleasure of seeing his countrymen at once seize the truths he revealed to mankind. *France*, for some years, rather through national prejudice than philosophical conviction, opposed his fame, and in their academies and universities continued to teach the opinions of their countryman *Des Cartes*.

Truth

Truth however at length prevailed, the cotemporaries of *Newton*, who might have opposed his merits from envy, being deceased, the succeeding generation adopted his discoveries, and his system now prevails in every polite part of *Europe*.

THUS far we have seen experimental philosophy continuing to improve; but it will be but justice to observe, that the successors of *Newton* have not since his time made that rapid progress in this science that was once expected. This judicious philosopher knew precisely those parts of Nature, which admitted of geometrical applications. Nothing could be more happily conceived than his applying mathematical calculations to the heavenly bodies, upon which no natural experiments could be made, and the greatness of whose bulks and distances could more easily be measured by numbers, and conceal the minute deviations of Nature from universal theorems.

His

HIS followers, much less judicious, have expected more from geometry than the art could grant, and, by erroneous imitation, have applied it to parts of Nature, which are incapable of admitting mathematical calculations. Thus we have seen the force of muscular motion determined by numbers, the velocity with which the blood circulates calculated with geometrical precision, the fermentation of liquors has undergone the same scrutiny, and the most inconstant appearances of Nature have been determined with inflexible demonstration.

It would be absurd to deny the great use of geometry in natural enquiries; but sure it may be said, without offence, that mathematicians expect more from its assistance, than they have been hitherto able to find. If we expect to make discoveries in Nature merely by the helps of geometry, it is probable we shall be disappointed, as this art is rather fitted to give precision to discoveries already made,

made, than to conduct us to new. Though it may serve as a vehicle, through which to deliver our discoveries to others, yet it is seldom by this method that we have happened upon them ourselves.

HOWEVER, this may be, it is rather to accidental experiments, than to painful inductions, that we are indebted for the modern discoveries in this science. Electricity, magnetism, and congelation, have been rather the result of accident than of investigation. Of these we know but some of the properties, nor have we any substantial theory as yet concerning them. In fact, mankind at last begin to perceive, that our knowledge of Nature is much more limited than we lately imagined it to be. In the last age it was fashionable to suppose, that we could satisfactorily account for every appearance around us: at present, the real philosopher seems to rest satisfied, that there is much in this science yet to be discovered, and that what he already knows

knows bears no proportion to what remains unknown. He no longer therefore pretends to assign causes for all things, but waits till time, industry, or accident shall bring new lights to guide the enquiry.

CHAP. I.

Of Matter and its Properties.

LET us for a moment compare this universe to a palace, erected by the divine Architect, and the unphilosophical spectator to a foreigner, who sees but the external part of the building. From so superficial a view it is evident he can have but an unsatisfactory idea of the skill and contrivance of the great Designer; he may perceive its beauties, but can have no idea of its conveniences. To have a more exact conception therefore, it is necessary to enter the building, to view each apartment separately, to consider the convenience of every room singly, with the symmetry and elegance of the whole.

IN the same manner the beauties of Nature strike our view, we find our curiosity allured by a variety of objects. Animals, vegetables, minerals, air, water, and fire, all put on different appearances to please, assist or astonish us; in order to come at a knowledge of their nature we must approach them closely; we must first consider each as divested of all their accidental qualities of figure and colour, and turn from Nature's external ornaments to view her internal simplicity.

IN this search, the first thing we find is *Matter*, that inert substance which serves as the foundation of all bodies, and which, while itself is unseen, gives existence to all other qualities that strike the senses. Of this all bodies have been originally composed, and it is probable that whatever different forms things may assume either in earth, air, fire, or water, yet matter is alike simple in all, and that every part of nature is composed from similar materials.

How-

HOWEVER this be, certain it is, that no efforts of ours can make any alterations in matter, though we easily can in the sensible qualities with which it is cloathed. We may, for instance, destroy the figure and colour of a globe of gold, and dissolve it into a fluid like water, yet still every part of matter in it remains unchanged, and fills up as much space as before. If we should attempt to force any other body into the place it possesses, the united strength of millions would not be able to prevail till itself were removed, to give the forcing body admission. If the softest substances, such as air or water, be fixed between our hands, these cannot be brought to touch, till the air or water find a vent on one side or another. The academy of *Florence* having enclosed water in a globe of gold, pressed it by the extreme force of screws on every side. The fluid thus compressed by the approaching sides of the engine, at last, finding no other passage, oozed out through the pores of the metal, and stood like a dew upon its surface. Thus

no art can destroy that property of body by which it keeps out all others that tend to enter the place it possesses; and which is called *solidity*.

ANOTHER property which cannot be separated from mere matter, is its *inactivity*, or that incapacity it has to move of itself, or to stop its own motion. It is true, we may easily put one body into motion, which may communicate the same to another, which may communicate to a third, and so on; yet still this matter is perfectly inactive, it only goes forward with the force impressed at first by ourselves, and whatever motion it may communicate, it loses so much of its own. No art, however, can give it a power of creating or generating new motion; a stone till removed will continue to lie inertly on the ground, and if thrown forward will continue to move forward till the air or some other obstacle hinders it from proceeding. If there had been nothing to stop its motion, it would continue to go on for ever.

As

As we are capable of giving *Motion* to matter, so also are we able to divide it; for *Division* is, properly speaking, only the moving of one part away from another. This *Divisibility* may be carried to great lengths by art: a single grain of musk shall so divide its parts as to fill a whole room with its odour, and yet lose but little of its weight in the experiment; a single grain of gold shall cover a surface of thirty yards square; a single grain of copper shall give a beautiful blue tincture to many millions of times its own quantity of water. Thus matter is extremely divisible; and after all, when the artist is thus fatigued with dividing a body into minute parts, the imagination can easily take up the task, and continue the operation without ever coming to an end,

LET us then call *solidity, inactivity, the capacity of receiving motion, and divisibility*, properties of matter of which it can never be deprived; properties which we mention here rather for the sake of

method than information; since they are all obvious to the most superficial observer, and since every moment's experience convinces him of their existence. In such subjects the learner wants to be informed of little more than the import of the names, for the things themselves they knew before. In fact, each of these properties implies the existence of all the rest; for if a body has been *divided*, it must have been put into *motion*; if put into motion, it must have been in a state of *inactivity*; if inactive, it must have resisted the pressure of the moving force, and the resistance to this pressure implies *solidity*.

CHAP. II.

Of Attraction.

THE properties of matter, mentioned in the last chapter, are such as offer themselves to every observer, and which can be known to reside in every single part of it, independant of the rest;
for

for I can feel, move, and divide a piece of wax or an apple, though there were no other in the world. But, besides these, there is another property of matter less obvious, and which, though residing in every part of body singly, yet cannot be made known to us, but by the operation of one body upon another. The property I mean is *Attraction*, or that power by which we see one body approach another, without any apparent force impelling it. Thus we see motes and straws, of themselves, fly to amber or sealing-wax, at a considerable distance; we see iron move towards the loadstone, and water to glass. What it is that thus impells these substances to approach each other, or in other words, what it is that causes this attraction between them, remains a secret that human sagacity has not yet discovered; we are certain of the fact, we see plainly that the substances do approach, and all that we can assign as the cause of their coming thus together is but conjecture.

IT may be asserted, for instance, as the cause of this, that there is an extremely subtil fluid, much thinner than air, which is diffused throughout the universe, and even enters the pores of the hardest bodies. This being granted, it follows, that such parts of this fluid as are thus strained through hard substances, must be necessarily much finer, and more subtil, than those parts of this fluid which are diffused into spaces less crowded with matter; as the liquor that is filtered through the pores of a marble rock, must be much finer than that which is unfiltered. Wherever this fluid is most dense, therefore, it will drive all solid bodies towards those places, where they find the least resistance; namely, where the fluid is least dense; that is, to the surfaces of the hardest bodies; and the particles of this fluid being also supposed elastic, its impelling force will be increased to what degree the imagination thinks proper to give it.

IT

IT was thus that *Newton* attempted to explain this appearance in nature*, a method of accounting for things, perhaps, originally borrowed from *Des Cartes*, and which wants only to have the existence of a subtil fluid proved, to make it bear the resemblance of truth. In fact, in other parts of his works, he seems to lay no stress upon this theory, and asserts, that a body attracted, is drawn in proportion to the quantity of matter it contained; while bodies impelled by a fluid, are driven with more or less force in proportion to their surfaces.

BUT though we cannot account for the cause of this attraction, or this tendency of one body to another, yet the experiments that serve to prove it are incontestable, though we shall find it various in different substances. The wonders of the *load-stone*, of *electricity*, of *capillary tubes* and *cohering bodies*, will at once confirm the existence of attraction, will

* *Optic*. p. 325.

excite our surprise, and will introduce us to more important discoveries.

CHAP. III.

Of the Magnet or Load-stone, with the attraction of Magnetism.

THE power which the load-stone has of attracting iron, or of one load-stone attracting another, has excited the admiration of every age; and even induced some of the ancients to assert, that it was an animated substance. *Aristotle* assures us that *Thales*, the most ancient philosopher of Greece, made mention of it, and *Hippocrates* speaks of it under the title of *the stone which attracts iron*. *Pliny* was struck with the wonders of its attractive qualities, which was all the ancients knew of it, and thus finely exclaimed *, *What can be more rigid,*

* Quid lapidis rigore pigrius? Ecce sensus manusque tribuit illi natura. Quid ferri duritie pugnacius? Sed cedit & patitur moves: Tratur namque a magnete lapide domitrixque illa rerum omnium materia ad innane nescio quid currit, *Plin.* l. 36, cap. 16.

and

and inactive than stone? Yet, for all this, nature has granted it sense, and power? What can be more obstinate than the hardness of iron? Yet it is brought to obedience, and becomes tractable. For it is commanded by the load-stone, and that substance, which conquers all things, flies to something, I know not what, incorporeal. In fact, these powers might well excite surprize, they were inexplicable from the beginning to this day, and remain so; posterity, instead of being able by experiment, to investigate the cause, have only by the search, found out new wonders equally inexplicable; therefore all that now remains, is rather to sum up the qualities of the load-stone, than to account for them,

EVERY load-stone hath two poles, in which, the greatest share of its magnetic or attractive virtue resides. These poles, or opposite points, may be found out by rolling the load-stone in the filings of iron, by which the filings will be soon seen to adhere to the poles, in greater
abun-

abundance, than to the other parts; and though it be broke into a thousand pieces, yet each part of it shall still have its poles, as before.

THESE two parts of the load-stone have received their name from the two poles of the earth, and like them, one is called the north, and the other the south pole. Nor are these terms applied arbitrarily; for they have a most sensible affinity with the poles of the globe, whose names they bear. A load-stone, so contrived as to float upon smooth water, (which may easily be done by making it with a broad surface) will have its poles always directed, each to its kindred pole of our earth; one to the north, and the other to the south. And if they be turned never so often, so as to make them point in different directions, yet the instant this external force is taken away, they will recover their former position,

THIS polar direction was utterly unknown to the ancients, but has by the
moderns

moderns been converted to the most useful and amazing purposes. For another property of the load-stone is, that it communicates its virtues to iron, merely by rubbing; and converts it, to all intents and purposes, into a magnet like itself, with all the same attractive properties. A piece of iron, thus impregnated with the magnetic power, and nicely suspended on a sharp point, so as to lessen the friction, and to give it the greater advantage of playing and turning in every direction, becomes what is called the *mariner's needle*, and will be seen to settle itself in a direction nearly north and south. It scarcely need observe, how absolutely necessary such an instrument must be in directing mariners in long voyages; and it was for want of it, that the ancients were obliged to coast along in their courses from one country to another; and seldom ventured to leave sight of land.

BUT though load-stones, or iron impregnated with magnetism, have a strong attractive

attractive force upon each other, yet they have a repulsive force also; for if we should attempt to make the two north poles, of two different magnets, approach each other, we should soon perceive them to fly off with some violence, as if afraid of the touch; and in the same manner also, would the two south poles repel each other: so that in fact, two magnets only attract mutually, by the poles of different denominations; that is, the north pole of the former, will attract only the south pole of the latter; and the north pole of this, in turn, will have the same influence upon the south pole of the other. But two poles of the same name, like two men of the same trade, are ever at enmity, and repel each other.

It is for this reason; therefore, when a magnetic virtue is to be communicated to iron, that the south pole in the load-stone, ever gives a north pole to the impregnated body; as we see, for instance, that end of the mariner's needle, which is touched by the south pole of the stone,

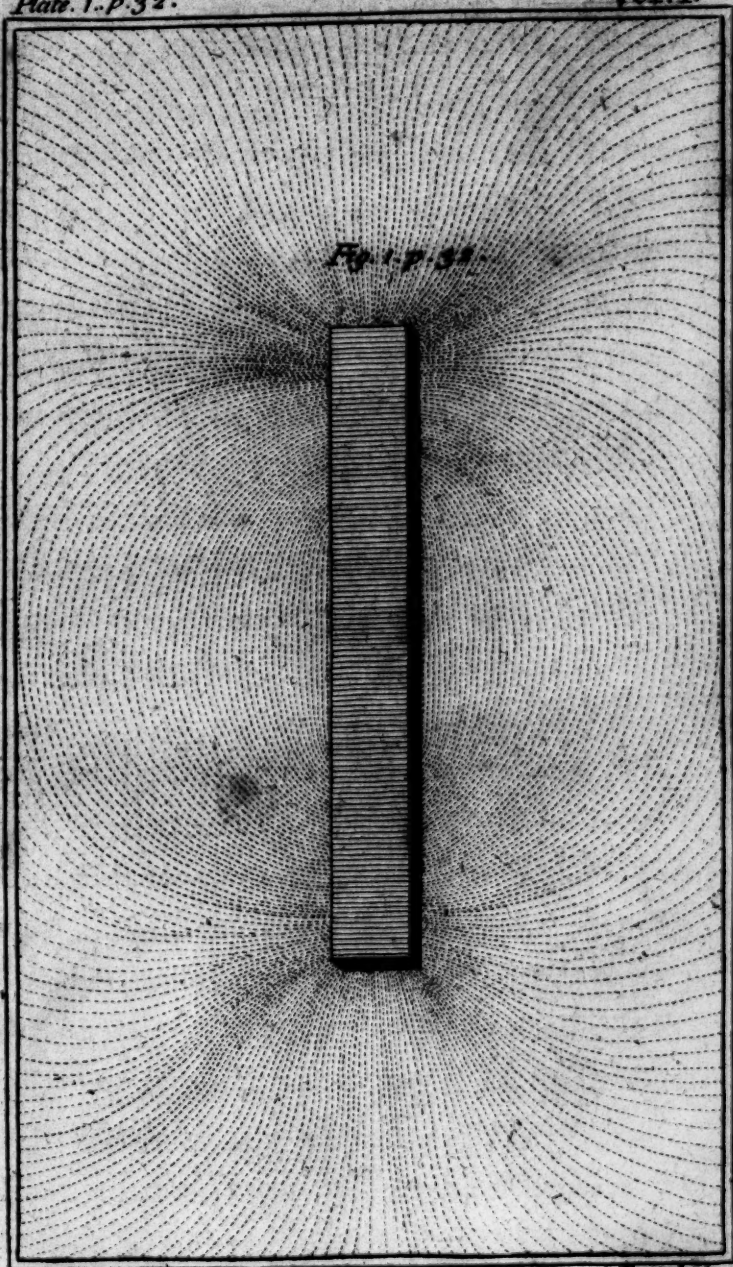
always points northward. There is therefore somewhat friendly and sympathetic, between the two poles of different denominations. Universally, when artificial magnets are made by rubbing, each pole in the making magnet, begets its sympathetic pole of a different name in the newly made magnet. And when two magnets are left to remain together, they should always be placed with their sympathetic, or opposite poles together, like pins that lie head to point, and this rather encreases their energy; whereas, if they lie with their disagreeing similar poles together, their power will be weakened, and at last totally destroyed.

THE fineness of these magnetic effluvia is such, that they pervade the hardest bodies; a magnet attracting iron, though glass, gold, water, or any other substance be interposed between them, and equally operating, *in vacuo*, as in open air. There is a curious method of rendering the directions of these effluvia visible. Strew some steel filings over a sheet of
white

white paper, and underneath, let a magnet be placed; then gently tap the paper with the finger, or otherwise, so as to give the filings a little motion, and they will soon be seen to form a regular striated figure upon the paper; as represented in the diagram. (See plate I.) From the regularity of the figure, which these effluvia assume, some have been of opinion, that the earth itself is one great magnet, sending forth effluvia in the same manner; and that all magnetic bodies, lying in the current of these, assume a polar direction: as a piece of timber, carried down a rapid stream, generally floats lengthwise.

HOWEVER this be, we find by experience, that the poles of a magnet do not point exactly north and south, but deviate a little from this direction; so that the mariner's needle often points some degrees away from the north pole. This is called the needle's variation; which, at different times, is greater or less in the same place, and often different in cold weather

Fig. 1. p. 32.



Froud sc



weather from what it is in hot. This is one of those phænomena, which has long employed human sagacity to no purpose; the hypothesis even of the late Doctor *Halley* himself, being no longer treated with esteem. He was of opinion, that the globe of the earth had four magnetic poles, and that the needle turned to which ever of those it approached most nearly. Then as its variation was continually found changing, as has been observed; being one time greater and another time less; so two of the earth's magnetic poles were always moving, while the other two were fixed. For this purpose, he has supposed the globe of the earth to resemble a nut, with its kernel; the kernel having two poles, and the shell two more; the kernel and its poles going round with a slow motion within the shell, and thus causing the variation of the needle to be greater or less, at different times; the internal poles drawing it away from its direction to the external. The reader will, no doubt, smile at so complex a

system; but system making was the fault of the last age.

IT has been tried also, but with no better success, to determine, to what extent the same magnet diffuses its attracting powers; and it has been found, that one day, the sphere of its power is much more extensive than another; that upon one trial, it would attract steel filings, at fourteen feet distance; and upon a second, it could scarcely reach them at seven feet, without any apparent alteration in the weather. Some magnets also are found to act with much force upon bodies near them; but with very little, if they are removed to the least considerable distance; while others are remarkable for contrary properties, having an extensive reach, though no great force in approximation or contact. Doctor *Helsham's* load-stone attracted iron four times more strongly, at one inch distance, than at two; or in a similar proportion. Sir *Isaac Newton's*, attracted six times more strongly, at one inch, than at two; while

while that of M. *Du Tour*, attracted but twice as strong, at similar distances. For this reason, no general law can be formed concerning the increase of magnetic power; the properties in each magnet being so very various, and often the same magnet, at times, differing sensibly from itself.

BUT, besides the virtue given to iron by rubbing upon a magnet, it may acquire the same powers, without the assistance of any load-stone whatsoever; and the best needles may be made artificially, merely by rubbing against other iron. A piece of steel, for instance, rubbed hard, for some time, all one way, by a polished steel instrument, will, by this kind of friction, conceive so great a degree of virtue, as to become an artificial magnet; of greater force than the natural one. Or, if a bar of iron be left to stand for a long time, in the same unaltered perpendicular position (as we see the bars of windows) it will acquire a magnetic power, and attract iron. But there is

a method, which gives a power to steel, far beyond what the natural magnet is able to produce; and which may be performed as follows.

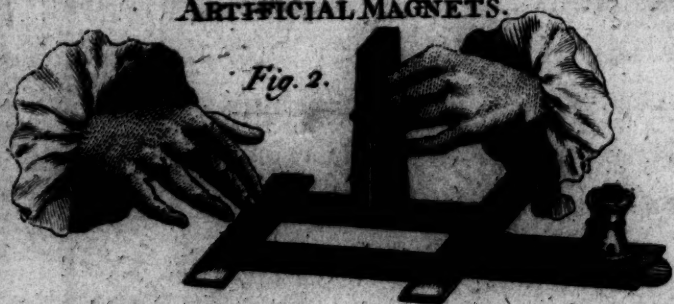
PROCURE a dozen bars, six of soft steel, each three inches long, one quarter of an inch broad, and one twentieth of an inch thick; with two pieces of iron, each half the length of one of the bars, but of the same breadth and thickness; and six bars of hard steel, each five inches and an half long, half an inch broad, and threentwentieths of an inch thick; with two pieces of iron, of half the length of one of the bars, but its whole breadth and thickness. And let all the bars be marked with a line round them at one end.

THEN take an iron poker and tongs, the larger they are, and the longer they have been used, the better; and fixing the poker upright, between your knees, bind one of the soft bars towards the top of it, with a silk string, which must be held



ARTIFICIAL MAGNETS.

Fig. 2.



p. 37

Fig. 1.

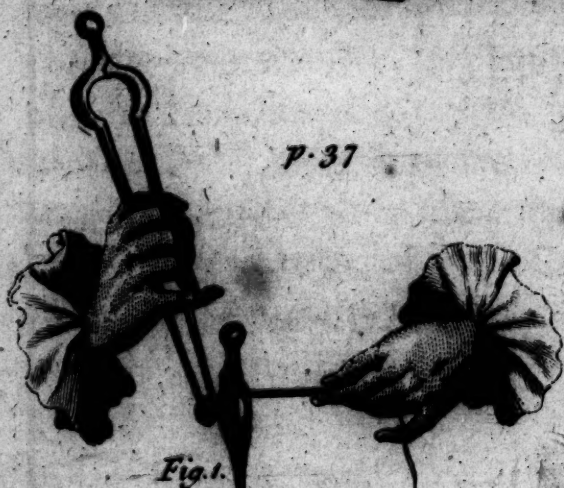
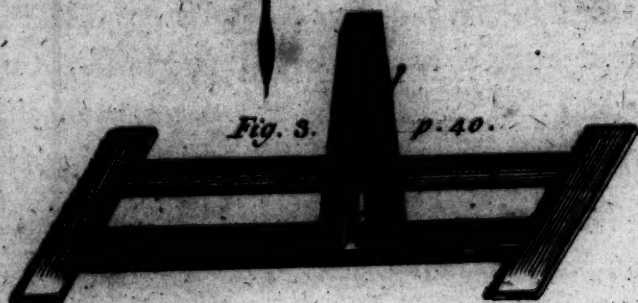


Fig. 3.

p. 40.



Freundt

held tight with the left hand, the marked end of the bar being downwards. (See Plate II. fig. 1.) Then grasping the tongs with the right hand, a little below the middle, and holding them upright also; let the bar be stroked by the lower end, from the bottom to the top, about ten times, on each side, which will give it a magnetic power, sufficient to lift a small key at the marked end; which end, if the bar was suspended on a point, would turn towards the north, and is therefore called the north pole.

FOUR of the soft bars, being impregnated after this manner, lay the other two parallel about one fourth of an inch from each other, on the table, between the two pieces of iron belonging to them; a north, and a south pole, against each piece of iron. (See Plate II. fig. 2.) Then take two of the four bars, already made magnetical, and place them, with their flat sides together, so as to make a double bar in thickness; the north pole of the one, even with the south pole of the
D 3 other.

other. Then lay the two remaining ones, on each side of these, so as to have two north, and two south poles together. You must then separate the two north, from the two south poles, at one end, by thrusting a large pin between them; and place them perpendicularly, with the separated end downward, on the middle of one of the parallel bars; the two north poles towards its south, and the two south poles, towards its north poles. In this position, slide them backward and forward, three or four times, the whole length of the bar, and finishing in the middle; remove them from the middle of this, to the middle of the other parallel bar, and go over that in the same manner; and turning both bars the other side upwards, repeat the operation. This being done, take the two parallel bars from between the pieces of iron, and placing the two outermost of the perpendicular touching bars, in their room; let the remaining two now be made the outermost, and those that were parallel become the innermost of the four to touch with.

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The process with these, being repeated as before, till each pair of bars have been touched three or four times over, which will give them a considerable magnetic power; put the half dozen together, three poles on one side, and three poles on the other; and in the former manner, touch with them, the two pair of hard bars placed between their irons, at the distance of about half an inch from each other. Then lay the soft bars aside, and with the four hard ones, let the other two be impregnated, holding the touching bars apart at the lower end, near two tenths of an inch; to which distance, let them be separated after they are set on the parallel bar, and brought together again, before they are taken off. With this precaution, proceed in the method described above, till each pair has been touched, two or three times over.

THE bars, though now impregnated with strong power, yet may receive still greater, by touching each pair, in their parallel position between the irons, with

two of the bars, one in each hand, held horizontally; (see Plate II. fig. 3.) and a north and south pole being approached to each other, and laid upon the middle of the parallel bar, the hands are drawn asunder, sliding the north pole of one touching bar, to the south of the parallel; and the south pole of the other touching bar, to the north pole of the same. This is repeated three or four times, and it will make the bars as strong as they can possibly be made. The whole of this may be gone through in half an hour, and each of the bars, if well hardened, may be made to lift above two pound; a power, much greater than any load-stone can confer. Such a method therefore of communicating magnetism, will answer all the purposes of navigation, and experimental philosophy in the compleatest manner, with less trouble, and more certain success.

As the magnetic power may be thus easily communicated, so may it as easily be destroyed. By making the load-stone

or

or iron red hot, the power is quite taken away, though it often returns upon the body's growing cold. A smart blow of a hammer, often dispatches this virtue also; and in general, any operation which alters the form or texture of the body, diminishes the magnetic power. Thunder sometimes gives it, and sometimes takes it away; in short, nothing can be more uncertain and capricious, than the phænomena of this amazing power. Almost every new experiment on the subject, discovers new wonders, some of the most striking are here mentioned; it would take up a volume but to name those that remain *.

* The phænomena of the dipping needle, have not been mentioned here; as some have of late began to doubt the reality of its existence; it may be therefore proper to leave that matter untouched upon, till that contest be determined.

CHAP. IV.

Of Electricity.

A Magnet attracts iron, without any previous rubbing, and its effluvia pervades the pores of all other substances, how dense soever. But, beside this, there are other bodies which attract different substances, tho' they require some preparation to make their power sensible; and the effluvia which they emit, can pervade only some particular substances. This species of attraction is called *Electricity*. For upon rubbing amber, called in Latin *Electrum*, it is found to attract any very light substances that are near it; and this property was known to the naturalists of antiquity, as well as the moderns. Upon further enquiry it was found, that not amber only, but several other substances, had the same properties, in a high degree; that glass, resinous substances, wool, silk, and hair produced the same effects. That any of these, when dry, and rubbed

bed for a short time, were always seen to attract motes and straws to their surface, from a pretty considerable distance; and sometimes repel them again with equal force. The same trials were made upon other bodies, most of which, after being very well dried and rubbed with long perseverance, shewed a similar power of attraction. Two kinds of substances alone were to be found in nature, that could not become attractive; and these were fluids, which could not be subjected to the trial of rubbing; and metals, which by no arts used could be brought to shew any signs of this electrical property.

As some bodies were thus perceived to have these electrical properties more easily excited in them than others, those which quickly became attractive by rubbing, were called electric bodies. Of this kind, were all precious stones, glass, porcelane, resins, bituminous substances, wax, certain parts of animals, such as silk, feathers, hair, or wool; all these easily becoming electrical, when rubbed,

rubbed, and exerting their power in a high degree. On the contrary, those which took a long time to have this property excited, or which shewed no signs of it at all, received the name of non-electric bodies. Of this kind, were all fluid substances, such as water, spirits or mercury; all metals, and semi-metals, marble, lime-stone, all living animals, all green plants and trees, and substances made from them; such as thread, paper, and linen cloth.

SUBSTANCES being thus classed, according to their electrical powers, it was then tried to how great a degree, bodies of the electric kind, such as glass, for instance, could be impregnated with an attracting power. A glass tube, about an inch and an half in diameter, and three feet long, being heated by rubbing, was found alternately to attract and repel all light bodies, at several inches distance. As this, however, was but a trifling power, instead of using a tube, experimental philosophers procured an hollow globe of glass,
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moderately thick, and about a foot diameter; which being made to turn upon an axle, in the manner of a cutler's grind-stone, and like that, being whirled round by means of a large wheel and strap, the palm of the operator's hand kept dry by a glove, or *Spanish* white being kept upon it, a great degree of friction was thus excited. The globe being rubbed in this manner, was seen to acquire a very great electrical force, and Doctor *Helsbam* long since found, that woollen, or filken threads, being held on one side near it, while thus turning, they would dart themselves into so many straight lines, all pointing towards the center of the globe. The effluvia were even perceivable to the smell and the touch; and these were the first steps, which were made in pursuit of the wonders that were afterwards discovered, in this part of philosophy.

IF, while the globe was thus turning, or soon after, it was touched with a piece of sealing-wax, resin, amber, or any other electrical substance, this made no alter-

alteration in its effects; the globe continued to attract leaf gold, motes, or straws, as before: on the contrary, when it was touched with a man's hand, a piece of metal, a stick, or any other non-electric body, all its attracting power ceased in an instant, and it required to be rubbed anew. It was, however, soon after perceived, that if the touching non-electric body, was placed in such a manner as to touch nothing but the electrified globe or tube, and to have no communication with any other body, it then became electric itself, attracted motes and straws, and its touching did not in the least diminish the efficacy of the glasses attracting power. If, for instance, a piece of metal, or any other non-electric body, was fixed on the top of a glass tube, taking care that it touched nothing but the glass only; and then the tube, being electrified, by rubbing with the hand, the metal above was seen itself to become electric; and like the glass to attract and repel light substances; and like it, when the finger was brought near

it, about the distance of half an inch, to snap and crackle. But if the metal, while it touched the globe, touched also the earth, or any other non-electric body that communicated with the earth, as a man standing on the ground, a chair, a table, or such like, all its new acquired virtue, instantly ran into the man, or the table, and from thence down to the earth; where, like spilled water, it vanished, and was lost in an instant, and was no longer capable of its former exertions.

IN order, therefore, to stop this current of electrical effluvia from running into the ground, something was to be placed between the man's feet and the earth, that would prevent the electrical effluvia from going any farther. Now it was found, that all electrical substances could do this; for though they become electrical by rubbing themselves, yet they never admitted the effluvia from another electrical body, but resisted its further progress. If, therefore, a cake of resin, wax, or
any

any other strongly electrical substance, be placed under the man's feet, while he touches the electrified globe, he becomes filled with the electrical effluvia, which has no power to escape downward, as the cake resists it, and he is as capable of attracting light substances, to the surface of his body, as the globe itself. A piece of metal, instead of the man, will do the same, so will all non-electric substances.

IN general therefore we may observe, that the electrical effluvia can be poured into all non-electric substances at pleasure by communication; that they receive it simply, at the approach of the electric globe or tube, which is heated by friction, and communicate it to all other non-electric bodies, with which they are united, though this union should be never so extensive. On the contrary, electric bodies, whose power can be excited by rubbing, will receive no effluvia by communication from other electrified substances, but repel all their emanations.

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LET us now then suppose the whole electrical apparatus prepared, the glass globe turning swiftly upon its axle, by means of a wheel, and rubbed by the hand of the operator, while the person to be electrified stands upon a cake of resin, wax and sulphur, mixed together, of about fifteen inches diameter, while he touches the upper part of the globe, or some non-electric substance, that communicates with it. The weather being dry, and the room spacious, we shall see the following wonders ensue. In a few seconds, the man will be filled with effluvia; he will become perfectly electrical; his hands, and every part of his body will attract and repel light substances at four feet distance, and even farther, if the weather be extremely dry. Each of these little substances, such as straws, motes, and leaf gold, are at first drawn towards the electrified body with great swiftness, and then when they have been saturated with the electric vapour, and have become equally electric themselves, they are repelled with equal force.

WHATEVER non-electric body, the man electrified holds in his hand, becomes electrified like himself, provided it has no other communication but with himself, or some electric body, into which its effluvia cannot enter. And this extension of the electrical effluvia, instead of diminishing its quantity, seems rather to increase its force, as well in the man, as whatever he holds in his hand. So that if a thousand men should take hold of each other's hands, provided they be all placed upon cakes of resin, or some other electric body, the last man will be as soon electrified as the first, and the greatest number rather more strongly than one at a time. However, if any one of them have the smallest communication with a non-electric body, which leads to the ground, if, for instance, one of these thousand men should have a linen thread, reaching from the skirt of his coat to the earth, the whole effluvia would escape through that narrow conductor, to be lost entirely. If these men, instead of holding hands, should each hold

hold an iron chain between them, they will be electrified with equal velocity and success.

- IF now, the electrified man, who stands foremost, ceases to touch the turning globe, he will, nevertheless, continue for a good while impregnated with the electricity he has received, as well as all the rest to whom it has been communicated; however, their power of attracting and repelling light substances, will insensibly begin to diminish, till, after some time, it totally ceases. Metallic substances are found to hold this electricity, infused into them, much longer than animals; probably, because their electric matter does not transpire, as in animals, by perspiration. But to make all electricity cease in a moment, in either, it is sufficient just to touch them with any non-electric substance that communicates to the ground.

IF one, who is not electrified, brings his hand near the face of the person under the operation, he will perceive

the impresson of a fluid atmosphere about it; and continuing to approach his finger to some protuberant part, the nose for example, if the room be darkened, the finger and the nose will appear enlightened; and when they approach still nearer, there will proceed, from the person electrified, with some noise, a bright stream like fire, which will affect both parties at once, with a small sensation of pain, and which will be painful in proportion to the strength of the electricity. This stream will be equally produced by the touch, from any part of the body, and even through the clothes; all that is required, being only that the touching person be not electrified himself.

IT is by this small stream, that the effluvia migrate from one body to another; so that if the barrel of a gun, or any other metallic body which is non-electric, be suspended by silk cords which are electric, and stop the progression of the effluvia, it becomes electrified, by a single touch from the man, under the operation; and what is more extra-

ordinary, the greater this non-electric body is, the more powerful is its electricity.

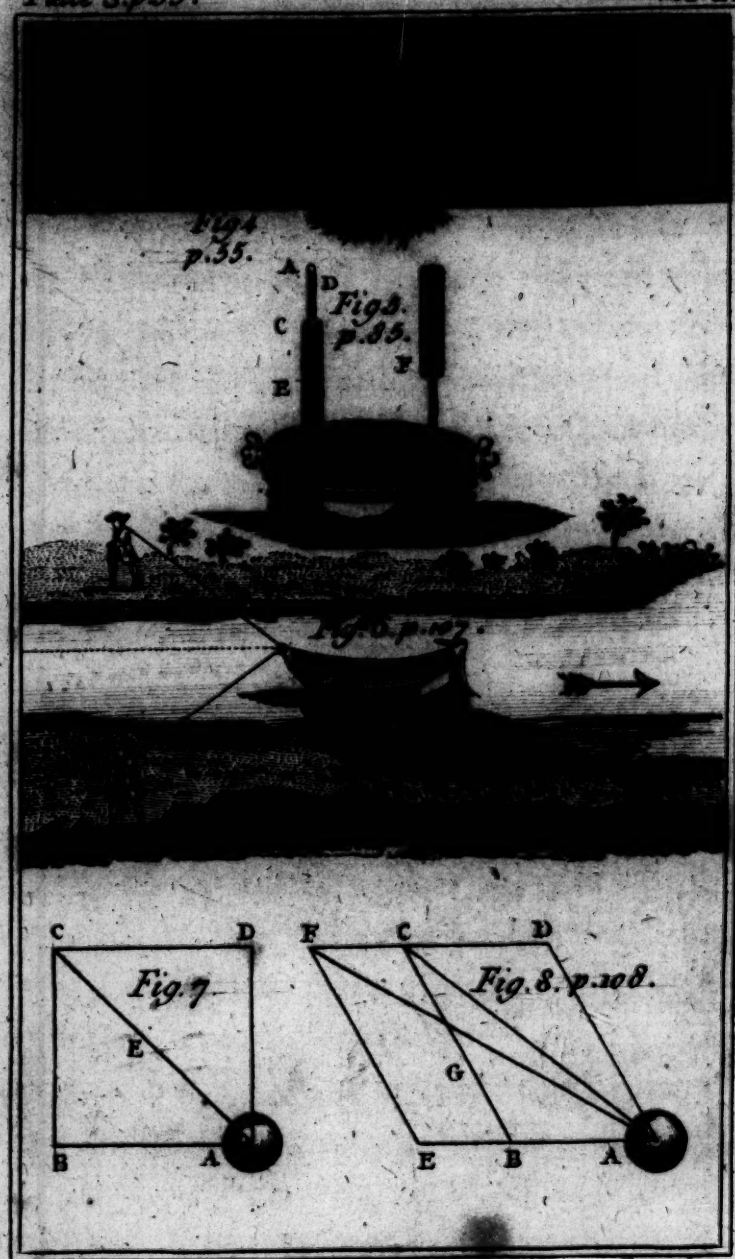
If a steel wire of five or six hundred yards, be suspended in like manner, by filken cords, the instant it receives electricity at one end, it is felt at the other; for the remote end will be found to attract leaf gold, the moment the nearer end touches either the man or the globe; and the effects, thus instantly excited, may be as instantly repressed, by the touch of a person who stands on the ground. If a man, standing on a cake of resin, should, with the point of a sword, approach the wire thus electrified, yet without touching, he becomes himself equally so; from whence it appears, that the effluvia can pass from one substance to another, without either coming into contact.

HITHERTO we have seen how electricity flows, either back or forward, with amazing velocity, and that it can be accumulated in any body at pleasure, by simple infusion. It will be found also, to

exert all these powers in a *vacuum*, or place free from air, with a greater force; for if a globe be placed in such a manner in a receiver, exhausted of its air, that it may still continue to be rubbed with the hand, while the rubbing continues, and while the air is kept away, the globe will send forth a very bright light, in great quantities; but its brilliancy will become more feeble in proportion as the air is admitted, though the rubbing should be continued all the while.

IF it be desired to give the electrical explosion still greater force, and to increase the quantity and brightness of the flame, more globes than one must be procured, all communicating with, and pouring their effluvia into one non-electric body. A long tube of white iron is generally made use of, for this purpose; as receiving the greatest quantity of effluvia, and retaining it longest, and easily conducting it wherever the operator's hand thinks proper. The flame that this iron tube, (or conductor let us call it) when electrified, sends forth at
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Prouds

the approach of the finger, resembles even lightning itself; it darts from the conductor to a great distance, to meet the finger, and occasions a smarting pain.

WHEN the conductor, or any other non-electric body, has been thus electrified, and has received as great a quantity of effluvia as it can bear, the overcharged effluvia, which is continued to be poured in from the turning globe, flows out, either from the whole surface, like a bright light, or from some point or angle of its surface, in a stream, like that which is excited by the approach of the finger. The flame resembles in form that of a hissing squib, (see fig. 4.) narrow upon issuing out, but diffusing its rays as it goes farther. If the finger be now approached to this stream, another wonder will appear. A stream of fire will proceed from the finger, in an opposite direction to the other; narrow upon leaving the finger, but diffusing its rays as it goes forward. When both flames have approached so near as that they join, they then quickly condense, and an appear-

ance is excited, that every way resembles lightning; the flash is sudden, the noise is loud, a sulphureous smell ensues, a great pain and shock is felt, and a slight burn remains upon the finger that sustains the experiment. We may kindle spirits of wine a little warm, gunpowder, or any other inflammable substance in the same manner, by holding them near a stream of fire, issuing from some point or angle of the conductor.

BUT the flame excited in this way, is but a spark, compared to that excited by the famous *Leyden* experiment; the cause of which, no philosopher has yet been able exactly to account for. A person holds by the bottom, in the broad of his hand, a decanter or bottle almost filled with water, in such a manner, as not to touch any of the empty part of the bottle with his fingers. Then an iron wire, that touches the globe or the conductor with one of its ends, is made to dip the other end into the water contained in the bottle, but so as not to touch the glass in any part. While the person holds
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the bottle thus, in the left hand, and the globe being strongly electrified, if he touches the conductor or the wire with the knuckle of his right, he will immediately feel a most violent shock ensue, the force of which seems diffused over his whole body; so great is its force, that Mr. *Muschenbrake*, who was the first who published this experiment, thought, when he first felt it, that it had killed him. This experiment was, some time after, improved by Doctor *Bevis*; who, instead of a bottle with water, made use of a large square pane of glass, and a different non-electric, namely, a metallic substance, in this manner. A large square pane of glass, of about twenty inches diameter, though the larger the better, is tinned on both sides, as we see the back side of a looking glass; on both sides however, there is a margin left all round untinned of about two inches broad. The glass being thus prepared, is placed flat upon a metal stand, so that the under side of the pane lies upon a non-electric body, which itself commu-
nicates

nicates with the ground. The upper side of the glass pane, is made to communicate with either the electrifying globe itself, or its conductor, by means of an iron chain. Things being thus disposed, the chain is strongly electrified by turning the globe, and thus communicating with the upper side of the pane, is electrified also. Now should a man be so rash, things being in this situation, as to touch the under surface of the pane with one hand, while with the other he touches the chain that communicates between the upper surface and the globe, the shock would be so terrible, that it would strike him dead in an instant. But to avoid this, the operator takes a bent iron wire, curved somewhat in the form of a C, which is fixed in a glass handle that prevents the effluvia from coming to his hand; he takes, I say, this wire thus bent, and blunted at both ends, and with this touches at the same time, the under surface and the upper chain that leads to the globe. The moment of the touch a flash of lightning ensues, which

dazzles the eyes with its splendour; the noise may be heard at a great distance, and its force is such, that it can penetrate several sheets of paper laid upon the upper surface of the glass, or melt leaf gold, when properly placed to receive the flame.

As nothing we have hitherto mentioned serves to explain the phenomena of this and the former amazing experiments, and as it in some measure departs from the usual laws of electricity; several very learned men have been much perplexed to account for it. Here we see glass, which in the usual instances is untouched by the electrical effluvia, in this experiment transmitting it, or at least, strongly affected by it. The *Abbé Nollet*, Doctor *Watson*, Mr. *Jallabert*, and Mr. *Franklin*, have all attempted to account for it, and each in a different way from the rest: it would be impertinent here to recite or confute any of their opinions, we shall only give an explanation later than theirs, namely, that of Mr. *Monier*,
who

who delivers it himself as a mere conjecture, and as such we repeat it. It is true, he says, that glass resists the admission of electric effluvia, when those effluvia touch its surface but in one or two points; but when it is united with a non-electric body, sending forth its effluvia more closely, so as to touch surface against surface; in such a case, the glass imbibes the effluvia like a non-electric body. For instance, as the surface of the water in a bottle, touches the internal surface of the glass in every part, when this water is strongly electrified for some time, the glass will also imbibe a part of the effluvia from the water. Now this being admitted, and experiments shew it to be true; after it has thus for some time imbibed the effluvia on its inner surface, this will make it begin to imbibe them on its outer surface also; so that if the bottle be held in the hand, it will also imbibe the effluvia of the hand. Now it appears, that this current of effluvia coming from the hand is greater than that coming from the water within; so that
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the two currents meeting in opposite directions, the stronger stream will overpower the weaker, and the whole current will run from the hand to the outer surface of the bottle, from thence to its inner surface, and so inward to the water. If now, while the whole bottle is thus imbibing the effluvia from the hand that holds it, the man, with the other hand, touches the conductor, and charges himself in this manner with a fresh quantity of effluvia, the whole torrent running towards the hand with the bottle; the hand that holds it will receive a most violent shock as the increased effluvia enters the surface of the glass, and at the same time that the other hand which touches the conductor, receives also a slight shock from this quarter, so that the whole body feels at once two concussions; and this produces the violence that is felt in the experiment of *Leyden*.

HOWEVER this be, the great resemblance which the flame thus excited, in every respect, bore to that which flashes
from

from thunder, gave philosophers the first hint of trying whether lightning was not actually the result of electricity. Upon examination, it was found that the air is often charged with vast quantities of electrical effluvia; that an iron wire suspended by electrical strings, often imbibed this fluid from the clouds in great plenty; that in times of thunder it was particularly charged with it, and often with so much more than it could contain, that the fluid streamed over from its points in great abundance. All this proved incontestably that lightning is no other than the electrical flash of some non-electrical uncharged body in the air touching another made electric by friction, or charged by communication. And this may be easily enough conceived, if we suppose a large quantity of dry air become perfectly electrical, and touched by a non-electric cloud, as in an iron conductor applied to a glass globe, the flash ensues, and the instantaneous loud noise is heard, which being echoed several times among the clouds, before it comes

comes to us, gives the continuing sound of thunder. If the flash should reach so low as the earth, and a person should unfortunately be in the place of its explosion, he is generally struck dead in a moment, and feels the most instantaneous of all kinds of death.

BUT this theory is not only amusing, but useful; for as in some countries the damages sustained by thunder are frequent and terrible, Mr. *Franklin* has invented a method of securing the houses, and consequently the inhabitants, from its violence. It is no more than procuring a long iron rod, which reaches from the cloud to the earth, and is so erected in or near a house, as to touch no non-electric substance whatever, except the ground below, and the cloud above. The end of this rod, touching the electrified cloud, imbibes the electric fluid with which the cloud is charged, and carries it down to the earth; where it is dissipated without farther mischief.

SOME other meteors are the result also of this electrical fluid. The *Aurora Borealis* for instance, or that shining light which is often seen by night in the heavens, and which the vulgar call streamers, may be thus accounted for from its effects. For it must be observed, that sometimes electric bodies suck in the electric fire, and sometimes they throw it out: if, for instance, after rubbing an unpolished tube of glass, you approach it with the finger, the stream of fire comes from the finger to the glass; if on the contrary, this tube be polished and then rubbed, the stream of fire will come from the glass to the finger. Now should we suppose, in the same manner, two electric clouds with different surfaces, and therefore one of them attracting the other's effluvia, if we suppose an intervening non-electric cloud as the conductor of the fluid from one cloud to the other, it will shine like the overcharged iron conductor, and put on the appearance of the meteor we attempt to account for.

FROM

FROM electricity also, we may account for that fire, so often seen by sailors, called *St. Anthony's fire*, which is nothing more than the electrical fire rushing into a place exhausted of its air, and there putting on a luminous appearance, as it always does in a *vacuum*. However, after all, in attempting to account for any of those meteors, we have but probable conjectures to support us; there is not hitherto enough known of the phenomena of electricity to build any system upon, and we are desirous of saying something rather to excite, than satisfy curiosity.

IT has not less embarrassed philosophy to account for the nature of this fluid, than to ascertain its properties. Some have supposed electrical fire to be a distinct fluid, as distinct from all others in nature, as the magnetic fluid is known to be; others will have it to be merely elementary fire, or such as is collected by the burning glass; others that it is a culinary; and others that it is no other

than the Ether of the ancients, or of Sir *Isaac Newton*, which is diffused through the whole system of the world; and the motions of which, give movement to all the rest of matter. To explain the resemblance between Ether and electricity, it has been in a former chapter observed, that this Ether is supposed to be in greatest quantity, or densest, in the most porous bodies; and on the other hand, more fine and subtil in dense bodies, such as gold. It is also known by experience, that upon heating or rubbing any substance whatever, it swells under the operation, grows bigger, and consequently becomes more porous. Now, say some, in proportion as the body becomes porous, the surrounding Ether rushes into it, and accumulates within, till the heat or the rubbing ceasing, the body gradually shrinks to its former dimensions, and the Ether is again ejected. Now this, they continue, is exactly what happens in electricity; the surface of the body is encreased by rubbing, the electrical fluid rushes into its pores, and there remains

remains for some time, till the effects of the rubbing ceases. And as the body; which by its dilatation receives this fluid, is, during the time of rubbing, continually taking in an overplus; and constantly, after the rubbing has ceased, by contracting itself, is squeezing out what remains, a part will be thus forced into whatever body comes in contact with it: it will, they say, be forced into all bodies that communicate, except such as have an extremely dense atmosphere surrounding them, which like a shell defends them from the incursions of this fluid that would thus force an entrance. But it is, they add, known by experience, that of all substances, those which contain light within them have the densest atmosphere; of this sort are glass, resin, diamonds, and in short, all highly electrical bodies. Bodies like these are ever found to resist the incursions of this fluid, except their pores are opened and their atmosphere rarified by rubbing. This dense atmosphere which surrounds them effectually, prevents the entrance of the fluid by

communication; and in like manner, when the fluid is introduced by rubbing, keeps it a long time shut up in the body, and prevents it from escaping. For this reason we find electrical substances never receive the fluid by the touch alone, but when they have been otherwise excited, they hold the fluid a longer time than non-electric bodies are found to do.

SUCH have been the attempts to reduce this part of philosophy into system: but philosophers have, in this instance, resembled architects, who begin to build before they have laid in proper materials. The experiments on this subject, though numerous and amazing, have yet produced no certain light, to illustrate the uses of electricity in the general system of nature; and even while we build one system upon the materials already procured, new experiments offer, to interrupt our progress. Mr. *Hamilton* of *Dublin*, let a slender brass or iron wire about five inches long be so placed as to
turn

turn upon a point like a mariner's needle, or as we see a turn-stile in the country. Let both ends be finely pointed, and half an inch at each end be bent in opposite directions till they are at right angles with the rest of the wire; so that it will form a figure somewhat resembling the letter Z, or rather this shape , the ends pointing neither up nor down, but in a plane with the surface of the earth. The stand or point on which this wire is made to turn must be two or three inches long, and must have its other end fixed in a small block of wood; then let the block with the wire be set in an electrified body, and the wire will turn round with great velocity, in a direction contrary to that in which the electric fluid issues from its points.

THESE are the outlines of the discoveries in electricity; a subject which has of late employed the attention of philosophy, and which is yet but in its infant state. Those various appearances which it assumes, probably arise from

some one leading cause, which is yet unknown : that it is of use in the system of nature, must be granted, for we find it hitherto, either medicinally or mechanically, of no peculiar benefit to mankind, and nature does nothing in vain. But what its uses in nature may be, whether it regulates her motions, or puts her into motion; whether it vivifies her productions, or continues their existence; whether it supplies animal heat or elementary fire, are subjects not yet illustrated; and may perhaps continue unknown while man sees but in part. Some of the conjectures on this subject are given; all would be endless.

C H A P. V.

Of the Attraction of Cohesion and Capillary tubes.

WE have hitherto seen attraction to prevail in every part of nature, that has fallen under our notice; magnets to attract bodies at a distance without rubbing, electric substances performing the same effects upon being rubbed: but besides these powers in nature of forming large masses by uniting bodies together, there is one of another kind, in which bodies that at the least sensible distance have no power of attracting each other, yet being touched together closely join and unite with a kind of sympathetic fondness.

WE perceive several bodies when applied to each other stick closely, while others, though united never so closely, or never so long, cannot be made to adhere after the force that kept them together is taken away. This power of cohesion,

by which bodies are held together, has perplexed the philosophers of every age, and every age has attempted the solution. Some have ascribed this tenacity of bodies, to a kind of hook'd formation in the atoms that composed them; so that two atoms like burs stick to each other, the hooks in one catching those of the other. As this however was explaining one difficulty by a still greater; *Bernouilli* ascribed all cohesion to the uniform pressure of our atmosphere. This theory he endeavoured to support by an experiment of two polished marbles, which would cohere in the open air, but would drop asunder in *vacuo*, or a place where the air was exhausted. But unfortunately for him, this fact happens to be false. Others were for ascribing cohesion to an occult quality in bodies, by which they aimed at a state of rest; and others again asserted, that the attempt at motion in all the parts of a body produced the rest of all, and thus they happened to unite into masses of peculiar

sizes and hardness. Such were the former weak attempts to solve this difficulty. *Newton* however saw, with the greatest degree of probability, that this tenacity of bodies might be produced by the same cause by which we see iron fly to the load-stone, or straws move to amber; in short, that it was produced by attraction, a cause unknown to us indeed, but of which, in numberless instances, we see the effects. The surfaces of all bodies, saith he, are unequal, which causes that they touch only in a small number of points, when placed one upon the other. The less unequal the surfaces of the bodies the more they touch, and consequently the more they attract each other. Thus we see, that those which have the evenest surfaces, have the greatest power of cohesion; and if, to render these surfaces still more uniform, the pores be filled up with some liquid, the power of cohesion will be still greater.

IN the same manner all solid bodies when brought into contact, as well as all liquids whatsoever, adhere to each other. These attract solid bodies, and are mutually attracted by them; from whence it appears, that this attracting power is diffused over all parts of nature, at least such as we have hitherto examined. If we apply the surfaces of two looking glasses to each other, being previously well polished, cleaned and dried, it will be found that they adhere to each other with a very sensible tenacity. The same effects will happen in *vacuo* (or a space emptied of its air) as well as in the usual manner. If two leaden balls be cut so as to have even surfaces, and they be pressed against each other with a twist, it will be seen that they adhere with a force equal to forty or fifty pounds weight. In general, all bodies whose surfaces are even will thus stick to each other, and if a liquid be smeared over either surface, their cohesion will be still the stronger.

IT

IT is this liquid or thick oil which is contained in the bodies of all plants and vegetables that holds their parts together; and we are taught by chymistry, that if this be burned away the rest will fall into ashes, and without the restoration of some other fluid, the parts cannot again be united. The bones of animals also, if calcined in such a manner as that all their oil should be exhausted, while their form is preserved, will be found to become extremely brittle, but they will in some measure recover their former strength if they be dipt in oil. Thus we find that some bodies are thus perceived to cohere, and to be more tenacious than others, by means of this fluid, or else from their internal conformation, by which the surfaces of every particle of matter contained in them, touch the surfaces of the neighbouring particles in the greatest number of points.

Muschenbroek has made many experiments to find the force with which the parts of many bodies are found to cohere
to

to each other ; or in other words, how much force is required to pull the parts of any body afunder, drawing them according to the length of their fibres. In these trials he found that the beech and ash were the toughest of all woods ; next to them the oak, then the linden and alder, then the elm, and lastly the fir ; the weight required to pull a piece of ash afunder, being more than double what was sufficient to break the fir. He also made similar trials on metals ; of these, gold was the most tenacious, then iron, silver, yellow brass, copper, tin, lead.

But bodies are found to attract each other at minute sensible distances, as well as in contact. If we place between two glass plates, such as those which have already been mentioned, a fine silk thread, then we may easily conceive those two plates will not touch, since they will be separated from each other by the whole thickness of the thread ; but however, notwithstanding this separation, the two plates will mutually attract

attract each other, though with less force than if there were nothing between them. Place between the plates two threads of the same twisted together, and afterwards three; the glasses will still attract, but with less force than before.

IT is by this power, saith *Newton*, that the small particles of bodies act one upon another, at small sensible distances, and cause several phænomena in nature. This opinion has been driven as far as it could well bear, by *Freind* and *Keil*, and been brought to explain all the theory of chymistry, as well as some other obvious appearances. Some bodies, say they, have a greater power of attracting certain kindred bodies than others. Thus water, in which the gall-nut has been dissolved, attracts the parts of iron, and forms the black liquor called ink; but if we pour into this ink spirits of nitre, with which the iron has a greater affinity, or by which it is more strongly attracted, then the iron, before dissolved in the gall water, flies to its
more

more kindred fluid the spirit of nitre, and sinks with it to the bottom of the vessel, leaving the water at top quite clear of any colour, except that given it by the gall-nut originally. If again we pour into this composition spirits of vitriol, between which and spirits of nitre there is the utmost affinity, the nitre spirit immediately quits the iron which it before united itself to, in order to join with the more kindred spirit of vitriol; and the iron, thus let free, is once more suspended like a black fluid in the gall-water, as before. By this method also of reasoning, we may account for all those changes wrought in the colour and tastes of liquors, upon their being mixed with each other. For whether they be naturally fluids, or only bodies dissolved or suspended in fluids, the kindred bodies fly to their peculiar kindred bodies. But if the affinity between the fluids and the body suspended, be greater than between the particles of the body itself, the body still remains suspended or dissolved; but if the parts of the body attract each other

other with greater force than the liquid attracts them, then they begin to crystalize, or to unite into masses of such figures as the peculiar kinds of salt are usually found to be. Lastly, when, continue our authors, upon the mixture of two bodies in the same liquor, which are both more strongly attracted by each other than by the fluid that surrounds them, they happen to strike against each other, if they happen to be elastic they will consequently be driven back with a degree of force almost equal to that with which they have been attracted; and this alternate attraction and repulsion will produce a fermentation in the whole. In this manner some *English* philosophers have attempted to account for many chymical phenomena; much has been objected against their theories, and the truth is, when examined closely, they have neither that precision nor perspicuity which subjects of this nature require; however, this disquisition belongs more properly to chymists than natural philosophers, and with them we leave it.

BUT

BUT to prove the attracting power of one body upon another beyond all possibility of doubt; if a glass bubble be set to float on water contained in a glass vessel, at a small distance from one side of it, though at first it appears motionless, yet after a very short time, from a state of rest it will begin to move towards the sides of the vessel, and that with a velocity encreasing as it approaches the power attracting, till at last, it shall strike the side of the vessel with some force. This approaching of the drop to the side of the vessel is also the more remarkable, as it in some measure moves up hill, the water in the glass vessel rising all round the edges, as is obvious to every minute's experience.

To shew this attracting power in an instance or two more. If two polished plates of glass, such as we have mentioned above, be both placed edgeways in water, their surfaces very near and parallel to each other, a small part of the
glasses

glasses being only thus immersed, the water will rise up between them, and the less the distance between the two surfaces of the glasses, the higher will the water rise. If the distance between them be about the hundredth part of an inch, the water will rise to about an inch; if the distance be but half that, the water will rise but half as high.

As water or any other fluid (except mercury) thus ascends between polished plates of glass, so it does likewise in slender pipes of glass open at both ends, (commonly called capillary tubes.) These capillary tubes of glass may be drawn to an excessive fineness, much slenderer than the finest wire of an harpsichord, by means of a blow pipe and candle. If one of these hair-like tubes be dipped at one end into water, spirit of wine, or any other convenient fluid, the liquor will rise to considerable heights, the narrower the tube the higher the liquor. This spontaneous elevation of the fluid,

which is in appearance contrary to its natural weight, demands our most particular attention. The body of man may be compared to an hydraulic machine, it it may be considered as a collection of tubes with their proper fluids running through each. In the almost infinite number of pipes which thus compose the human frame, those of the small capillary kind, are without doubt the greatest in number; for this reason therefore, a thorough knowledge of these, interests us the more.

THE subject is difficult, and requires patience and revision. The ascent of the fluids, in capillary tubes, has been by the best philosophers ascribed to the power of the sides of the tubes attracting the fluid; but there are some things which embarrass this opinion, and Doctor Jurin was the first who treated the subject with much accuracy and precision. Before the method of explaining this phenomenon was broached by Newton, some ascribed

ascribed the rising of the fluid in the narrow tube to the unequal pressure of the atmosphere; the air, said they, is composed of parts which stick to each other, and consequently cannot enter the narrow tube where it is open at the top, therefore not being able to press upon the fluid within the tube, as it does upon the fluid without, the fluid is pushed up by the external pressure being greater than the internal. This whole hypothesis is destroyed by a single experiment, for the fluid rises in *vacuo*, where there is no air, as well as in the ordinary manner.

ANOTHER set of naturalists have imagined, that upon the tube's being immersed in water, that part of the water in immediate contact with the internal surface of the tube, lost its weight downwards by its adherence to the sides of the glass; that it was therefore pushed upward by that part of the water immediately below it, which coming into the place of the former, lost its own weight

in the same manner, by adhering to the inner sides of the tube, and that thus successive columns of water were forced up and suspended. But if this system were true, the tube, by being plunged into the water in such a manner as would cause the fluid to adhere to it in greatest quantity, would be most filled with the fluid. However, the tube which is but slightly dipped becomes as well filled as that which is deeply immersed in the fluid. These systems being found inadequate to the purposes of explaining this appearance, later philosophers have had recourse to attraction, all agreeing that the fluid is attracted by the tube, but they differ in the part by which the tube attracts. Some have said, (such as *Hawksby* and *Morgan*) that the internal surface of the tube attracts the fluid and causes it to rise, till the weight of the fluid, so raised, becomes equal to that power; which thus lifts it above its level, and then it stops without rising. This explication, however, is by no means satisfactory; for, as

we have said before, the narrowness of the tube and the height to which the water rises are always in the same proportion; as for instance, if a tube the hundredth part of an inch diameter, raises the water to one inch, a tube the fiftieth part of an inch will raise just half an inch of water. Now the internal surfaces of the tubes cannot be the cause of the water's rising in either, for in the narrow tube, the surface applied to raise the water, is greater than in the wide one; whereas, in the latter, the quantity of water raised is greater; wherefore, if the surfaces were the cause of attraction, the greatest surface would raise the greatest quantity.

DOCTOR *Jurin* perceiving the insufficiency of this explication, has given one of his own; but first, a very remarkable experiment is necessary towards explaining it. Dip the tube A B (fig. 5.) of two different diameters into water. Though a tube of the diameter of the part C B could elevate the water only to the point
G 3 E, yet

E, yet if it be filled with water up to D, this water will not sink again, but continue suspended in the tube as high as if it were only of the small diameter of the parts A C throughout. By this experiment it is obvious, that the liquor does not remain suspended, by the attracting power of the whole internal surface, since here there is no proportion between the thing which raises, and the thing which is raised; the quantity of surface attracting, being very trifling in this experiment, and the quantity of water raised very great. Our judicious philosopher, therefore, is of opinion, that as the fluid rises in proportion to the diameter of the tube in its upper part, that it is attracted by that ring of the internal surface of the tube, which is touched by the upper surface of the fluid as it ascends. As this ring is narrow the water rises high, as it is wide the water sinks in proportion.

MR. *Clairault* is still for another hypothesis, and thinks the inferior end of the

the tube is the chief elevating power; like the former, however, he allows attraction to be the cause; but still it must be confessed that the laws of this attraction, at what distance it acts, or how the same acknowledged force is found to raise, in one instance, a large weight of water, and in another, is incapable of supporting a much less, are things not yet clearly made out; we know enough of the general appearances of capillary tubes, to ascribe their power to attraction; some exceptions only raise doubts, and teach us to suspend our entire assent; only still let us appear sensible that ignorance is better than error.

WHATEVER be the causes of the ascent of fluids in capillary tubes, the experiment is obvious, and in the explication of many parts of nature, we shall find the doctrine of fluids ascending in capillary tubes of great utility. The human frame, as we have already remarked, is a machine composed of numberless tubes of

G 4 different

different diameters, with fluids circulating through them. Through the largest of these, the force of heat, or their own power of contraction, or the impulse of the succeeding parts of the fluid driving on that before it, are the causes of circulation; but when the diameters of those vessels become so small as to lose all elastic contracting power, or when they are at too great a distance from the heart, which is the propelling power, or when placed at such angles that the succeeding mass of fluid no longer presses from behind, it is then that circulation is carried on in the same manner as fluids rise in capillary tubes, the minute vessels of the body taking the blood and other juices through them, by means of this capillary suction, if I may so call it, and then emptying themselves in the larger vessels again.

In the same manner, every plant and vegetable may be considered as a bundle of capillary tubes united, with their ends placed in the earth, from whence they imbibe

imbibe their moisture; and if each of these tubes be considered as indefinitely small, it is apparent that such will raise the fluids to any indefinite heights, so that the sap will rise by the same means in the tallest oak as well as in the lower shrub. But it may be asked, how some vegetables extract one kind of sap from the earth, and others a sap every way different? In answer to this it may be observed, that glass capillary tubes of all other fluids are found to raise water to the greatest height; now if we suppose every vegetable like the glass tube, thus endued with a property of raising some particular fluids to greater heights than others, we may, with equal propriety, suppose that some vegetables are so formed, as to raise only fluids of one particular kind, and that this is the cause of that variety which is found in their juices.

THE theory of capillary tubes has also been brought to explain the ascent of
liquors

liquors in a sponge, in a loaf of sugar the under surface of which is placed in water, and such like substances, which being porous, may be considered as composed of a number of little canals or tubes, each of which acts in the manner already explained. Perhaps this doctrine may also be of use in explaining the origin of fountains, the waters of which are thus imbibed by the earth, and rise through its substance till they come to its surface, to supply the necessities of man, or to adorn his habitations. As the earth may be thus considered acting like a sponge upon the waters placed below its surface, so the air has been compared to a sponge raising waters to great heights above its surface. This has been assigned as the cause of vapours, clouds, and exhalations. A sponge or capillary tube, when filled with its fluid, continues to attract no longer; in the same manner the air, when charged with rain, has no power of absorbing moisture, but continues thus charged till the cold condensing,

ing, it acts upon it like pressure upon a sponge, and thus obliges it to fall in rain.

WE could adapt this theory to the explanation of several other phænomena not yet well understood, but we would not embarrass the learner, in his very entrance upon this pleasing study, with unsupported conjectures. They who can wrest such experiments as these to explain all that they see, would, with equal ease, have explained appearances of a contrary kind, upon the very same principles; the causes of meteors are as yet but little understood, and in fact, for many years past, have been very little sought after.

CHAP. VI.

Of the Attraction of Gravity.

WE have hitherto seen an attraction prevail at sensible distances between iron and the load-stone; we have seen it prevail in a more general manner between electric and non-electric substances; it has been found existing still more generally in almost every body that can be subjected to experiment, operating most strongly in cohesion, and losing its force in proportion as the two bodies under experiment were removed from each other. If now, therefore, we would desire to enquire into the reason that all bodies continually fall to the surface of the earth, would we ask the cause that impells them rather downwards than upwards, the answer will be obvious, namely, attraction. The same secret cause that impells iron to the load-stone, or motes to amber, influences all bodies on the surface of the earth to fly to it. It is a rule adopted by philosophers and confirmed

firmed by common sense, that more causes than one are not to be assigned for similar effects; here we see nature operating in many instances entirely like her operations in others, and therefore we must account for her operations by the same rule in both cases. Let us, therefore, for a moment, consider the earth as one great attracting body, drawing like a magnet every thing to its surface; a stone when forced up into the air, by the strength of the slinger's arm, comes down again by the earth's attracting power; a cannon ball shot upwards, is brought back by the earth's influence, with almost equal velocity. Let us suppose, I say again, that the earth acts upon these bodies in a manner, similar to that with which amber acts upon straws, or a magnet acts upon iron. Let us be allowed this for a short time, and it will soon receive almost incontestible evidence from a variety of reasons.

To have an idea of this, let us begin by considering by what laws the attractive power

power of the globe, which we inhabit, may be supposed to be, and in fact is regulated. Let us then, first, conceive our earth as a great sphere or ball, and its attracting power as issuing forth from all parts of it in straight lines, as rays do from the sun, as heat from fire, or smells from a perfume; in short, diffused every way in right lines from the center of the globe under consideration. This being conceived, it is obvious, the force by which any body on its surface is attracted, will be greater or less in proportion to the quantity of the attracting rays; but all rays issuing from a center, recede from each other, as the square of their distance from that center encreases; that is, a body at twice the distance of another body, will be attracted only by a fourth part of the rays that attract the latter, at thrice the distance, with only a ninth part, at four times the distance, with only a sixteenth, and so on. Thus if I desire to know how much a body, which at one semi-diameter of the earth's distance weighs or gravitates four pound, will weigh at two semi-

semi-diameters distance; I take the increased distance two, and square it, that is, multiply the number by itself, thus, twice two is four, and then say, as this squared distance is increased, so much is the gravity or the weight of the body diminished; that is, the body weighs four times less than it did at first, *viz.* one pound. Now should it be asked how much this same body will weigh, at three semi-diameters distance, I again take this distance three, and square it, which is nine, and then say, that the body only now weighs a ninth part of its original weight; that is, six ounces, or thereabouts. In short, to say all this in different words, the force of gravity increases in a duplicate proportion as it approaches the attracting power.

ALL bodies upon this earth tend to it in a line perpendicular to its surface; the lightest will fall, if unsupported by some surrounding fluid, such as air or water, as well as the heaviest. The smoke of a candle which ascends in the

the air pump, before the air is exhausted, yet upon a *vacuum* being made, will fall down plumb to the bottom of the receiver. If we drop a piece of gold and a feather from the top of an exhausted receiver, they will both fall to the bottom at the same time; by which it appears that a body, which is ten thousand times heavier than another, yet is attracted with equal ease and celerity. The force, therefore, which has caused the heavy body to descend, has acted upon it with ten thousand times the degree of power which has been applied to move the lighter, in the same manner, as it requires ten times more strength in me to lift ten books than one. Gravity, therefore, acting in proportion to the quantity of matter in all bodies, and the earth, which is almost infinitely greater than all other bodies on its surface, acting with a comparatively infinite force, must attract all to itself, with almost an infinite degree of superiority.

BUT

BUT although these be the laws by which gravity acts, at considerable distances from the center of the earth, yet we cannot pretend to ascertain them by experiment; the difference, perceivable by us at the surface, is so small, that it scarce makes any alteration in the descent of bodies. We, on the surface, are distant from the center of the earth, near four thousand miles, and at the height of one mile, our distance will be four thousand and one miles; now should we regulate the difference of gravity by the squares of these numbers, they at the surface will find their gravity to be about sixteen thousand, and they a mile higher sixteen thousand and eight, a difference too small to be perceivable by our senses.

BUT though this difference is not perceivable by us, in the descent of bodies at the surface of the earth, yet when we ascend to the heavenly bodies, particularly to the moon, which we know by the means of the telescope, to be nearer

the earth than any of the rest, we shall find these laws of attraction to guide it in all its motions. We shall find that all the planets turn round the sun, which is infinitely larger than themselves; by the same law, we shall see those smaller planets, which are the attendants upon other planets, guided by the laws of gravity; if we measure their distances from each other, and the times of their travelling round their respective centers of revolution, we shall find all concur in proving that the larger bodies attract the smaller, in proportion to the difference of their quantities of matter, and that they are attracted the nearer they approach, with a force increasing, as the distance squared decreases. If this be true, and it will shortly appear that it is, the descent of bodies to the surface of the earth, receives a new proof of its arising from that power we call attraction. For if we find this attraction to prevail amongst all bodies in the heavens, as upon all on the earth, it would be bad philosophy
to

to say, that in the single instance of a body's falling to the surface of the earth, nature acted upon different principles, since natural effects of the same kind must be allowed to proceed from the same causes. If I see a stone gravitate here, and another gravitate or fall in *America*, I allow the fall in both to proceed from the same cause. But if I see the moon gravitate towards the earth, (as will shortly be seen she does) if I see the earth gravitate towards the sun, if I see his attendant planets gravitate towards *Jupiter*, if I see motes gravitate to amber, and iron to the magnet, it would be absurd not to grant that the same cause which makes all these gravitate or fall towards each other, makes also a stone gravitate or fall towards the earth; nature acts simply, and we should reason with a simplicity conformable to her operations.

C H A P. VII.

Of the power of Attraction in Celestial Bodies.

WE said that the laws of gravity prevailed in guiding the motions of all the celestial bodies of our system; an assertion which requires to be proved. However, as it is a subject which belongs rather to astronomy than natural philosophy, we must explain it with the utmost brevity. To enquire whether it be the same principle which guides the moon in her orbit, and makes an heavy body fall towards the surface of the earth, and whether they be moved by the same laws, it is first necessary to examine what space a body falling to the earth, would move through in one minute, and what space the moon, which is sixty semi-diameters of the earth distant, would move through in the same time; and if they are both found regulated in similar proportions, they may both be asserted to arise from one similar cause.

Newton,

Newton, the great inventor of the system, set himself diligently to measure both. He was taught that a body falling to the surface of the earth, ran through sixteen feet in a second, for this experiment had been made with exactness by *Galileo* before him. But in measuring the motion of the moon he had more trouble, for it was first necessary to know her precise distance from the earth, and to attain a knowledge of this, it was requisite to have the exact measure of our globe. In this he was led astray, for from wrong measures the geographers of that time were taught to reckon but sixty miles to a degree, whereas they should have reckoned seventy; these erroneous calculations therefore, were found by *Newton* utterly repugnant to his system, and he was willing to abandon his theory for a while, rather than force nature to conform to it. However, the true measure of a degree being some time after found out, *Newton* again resumed his calculations, and found them all agreeing with the utmost exact-

ness to the appearances of nature. The moon is sixty semi-diameters of the earth distant from us; now it is known by computation, that if the moon fell perpendicularly towards the earth, instead of being pushed round in a circle, it would at its present distance begin to fall at the rate of sixteen feet and an half in a minute. But in going through this space, it moves nearly thirty times slower than a body falling at the surface of the earth is found to do, which moves sixteen feet and an half in a second. The moon, therefore, falling at its present distance, and the body falling at the surface of the earth, fall by the same law, for the square of the moon's distance will be found exactly in proportion to the diminished force of its attraction. If the stone, which falls so swiftly at the earth's surface, were carried up as high as the moon, it would take half a minute in falling sixteen feet and an half, as the moon is now found to do.

THIS

THIS law of attraction which prevails between the earth and the moon, may be extended to all the other planets, and it will be found to explain their motions with equal precision. We shall find that the attendant planets are attracted towards their primary planets, and that they, earth and all are attracted towards the sun by a force increasing as the distance squared decreases.

BUT it will be said, that we talk of the moon's being attracted or drawn towards the earth, and the planets towards the sun, when in fact they only move round them in circles. If the earth or the sun, it may be asked, attract the celestial bodies towards themselves, why do they not fall upon their surfaces, as we see heavy bodies fall to the surface of the earth? To answer this, we must observe, that the great Creator of all things, when he first formed the universe, permitted all bodies that compose our system to be actuated by two different powers.

One, that inert force in matter, by which, when once moved, it would continue to go on in a straight line for ever, if not turned out of its way by some obstacle; the other, this power of attraction, by which every body tends towards some other. Now then, let us for a moment imagine that in the forming our system, the sun was first made and placed in the center; after this, let us suppose that the mighty Architect took this ball of earth and pushed it from him in a right-lined direction. It is obvious, that by its own inert force it would go ever straight forward into endless space, if nothing hindered; but while its impressed force drives it forward, the attraction it feels from the sun draws it with an equal degree of force inwards; and between those two opposite forces it is found to go wholly in neither, but as a stone whirled by a sling it describes a circle round the sun. That force by which a body endeavours to recede from the center of its motion, is called
the

the centrifugal force, that by which it tends towards the center is called the centripetal force; they both go by one common appellation, namely, that of central forces, which, if we would have a more precise idea of the manner in which the planets revolve about the sun, must be examined more minutely.

C H A P. VIII.

Of Central Forces, as far as they tend to explain the Universal System.

WE have often had occasion to inculcate, that matter is of itself entirely passive, incapable of moving itself, or stopping its own motion; a ball thrown by the hand would continue to go on for ever, did not the force of attraction, or the resistance of the air, at last destroy the motion it received from the flinger's arm. Matter, in short, follows whatever direction is impressed upon it, and is affected by every impulse in its way. As it is incapable of moving itself, so it is incapable of changing the direction of its own motion, that is, it must move forward in a straight line in the direction it first received. If then at any time we see a body moving in a circle, or any curve whatever, we conclude that it must be acted upon by two powers at least, one to put it into motion, and the other
to

to draw it out of its rectilinear direction, in which it would have moved on for ever. Let us therefore consider the direction a moving body will receive, that is put into motion by two powers at the same time. Suppose, for instance, a boat (see fig. 6.) is drawn up the stream of a river, by two men on opposite banks and with equal force on both sides; it is evident it would follow the direction of neither entirely, but go in a line between both, exactly in the middle of the stream.

To carry this yet farther, suppose a ship at A (see fig. 7.) driven by the wind, in the direction of the line A B, with such a force as would carry it to B in a minute. Then suppose a current driving this ship, at the same time, in the direction A D, with an equal force. By these two forces acting together at right angles, the ship will go in neither direction, but describe the longer line A E C, running from corner to corner in a minute;

minute; or in other words, it will describe the diagonal of a square.

IF these equal forces, instead of acting upon the body A (fig. 8.) at right angles, act in more conspiring directions, one having a tendency to drive it through the space AB, at the same time that the other has a tendency to move it through an equal space AD, it will then describe the diagonal AGC, in the same time that either of the single forces would have caused it to describe its respective side; and this, it must be observed, is a greater space than if the forces had acted upon it at right angles. Universally therefore, the more conspiring the united forces that drive a body forward are, the greater space the moving body will describe.

IN a manner similar to this, bodies revolving round a center, are attracted by two powers. If a leaden bullet, fixed to the end of a string, be suspended upon a pin, and then receive a blow from a battledore or other instrument, it will thereby

thereby describe a circle about the central pin, and while its circular motion continues, it will endeavour to fly off from the center; and in fact, if the string which holds it to the pin, happened to break, we should see the bullet fly off, and hit the wall, cieling, or some other part of the room; but it is held by the string, with a force equal to that by which it is drawn away; these forces, I say, are equal, for if one prevailed, the body would circulate no longer. Now the primary push, if I may so call it, which a planet has first received, resembles the blow given to the bullet; while the attraction, which draws it to the sun, the center of its motion, may be compared to the string.

Now let us find out the manner of comparing the forces of two planets revolving in circles, and this will lead us to greater precision. As the planet, by the two forces, revolves in a circle, and as all motion is naturally rectilinear, as we proved above, we must consider the circle,

cle, thus described, as a succession of right lines infinitely little; and such, in fact, are all the circles that we find in nature. Now the body which thus moves in a succession of right lines, would continue to go on in one of them, as in (fig. 9.) ABCD, if not continually forced down by the power which draws it to the center D. Instead, therefore, of a circle, let us suppose the body to move in a polygon, or a figure composed of a number of angles, which obstruct its motion as it revolves. Now it is evident, that the force with which the body moves along one of those small right lines, will be great in proportion as the quantity of matter it contains, and the swiftness with which it moves are great. And it is also evident, that the angular obstructions its force surmounts in a certain time, will be numerous, in proportion as its swiftness is great, and the circle, in which it moves, is small. In general, therefore, the body's central force will be great in proportion to its quantity of matter, to its swiftness.



Fig. 9. p. no.



Fig. 10. p. no.

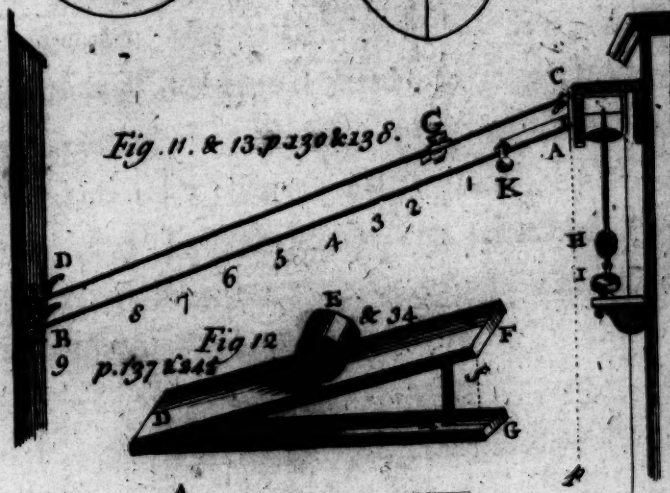


Fig. 11. & 13. p. 130 & 138.

Fig. 12 p. 137 & 141

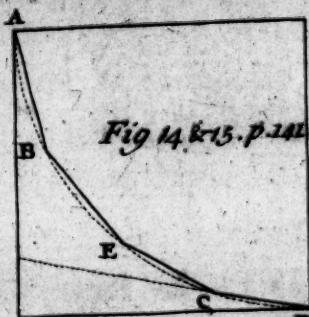


Fig. 14. & 15. p. 141. 142. 152.



Fig. 16. p. 142.



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swiftness, or to the quantity of angles surmounted in a certain time, and to the smallness of the circle in which it moves. In other words, we may estimate the central force of any body, by multiplying the quantity of matter, by the swiftness multiplied by itself, and by dividing the product by the semi-diameter of the circle described.

To illustrate this by an example: suppose I want to compare the central forces of two bodies of different magnitudes, different velocities, and moving in unequal circles. The first body weighs 2, has swiftness as 2, and moves in a circle, the semi-diameter of which is 2. The second body weighs 3, with a swiftness equal to 3, with a semi-diameter of 3. I take the swiftness of the first body, and multiply it by itself thus, twice two is four. Then I multiply this by the weight 2, and the produce is 8, this I divide by the semi-diameter 2, which
gives

gives 4. What has been done to the first body must be done to the second, and the result will be 9, and as 4 is to 9, the central force of one body will be to the central force of the other.

THIS being understood, if we apply this rule carefully we shall find, 1. that if two bodies of equal weight describe unequal circles in equal times, the central force will be greatest in that which describes a circle of the greatest diameter; and of consequence, if the central forces of two bodies, which describe unequal circles, are in proportion to their diameters, the two bodies will revolve in equal times.

2. IF two bodies describe unequal circles, their central forces will be directly as the squares of the velocities, and inversely as their diameters. From whence it follows, that if the velocities are equal, then the central forces will be inversely as the diameters alone; but if the diameters are equal, and the velocities unequal,

equal, the central forces will be as the squares of the velocities alone. And if the central forces of two bodies, which move in unequal circles, are equal, their diameters will then be as the squares of the velocities.

3. If two bodies moving in unequal circles have equal central forces, the time employed in describing the greatest circle, will be to the time employed in describing the least, in the same proportion as the cube of the greatest diameter, is to the cube of the less. But if the reader considers, he will find in this case the times and the velocities the same; but we observed before, that the diameters are as the squares of the velocities, therefore the diameters here are as the squares of the times.

FROM hence it follows, that in comparing the motions of the planets, and their distances from the center of their motions, this law has been established,

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I

That

That the squares of the periodical revolutions of two planets, are as the cubes of their distances from the center, round which they move.

THIS law is of infinite use to astronomers; for if they know the periodical time, that is, the time of the circular revolution, of two planets, and the distance of one of them from the center, they can by this find out the distance of the other, which before was not known. For instance, we know the periodical time of the moon to be 27 days, and the periodical time of the earth to be 365 days. The distance of the moon from the center of its motion we also know to be 60 semi-diameters of the earth. Now I desire to know the distance of the earth from the center of its motion, namely, the sun? I know by my rule, that the proportion of the squares of the periodical times, will give the proportion of the cubes of the distances. Then I find out the squares of the periodical times of the two planets.

The

The periodical time of the moon is 27, and the square of that number 729; the periodical time of the earth is 365, and the square 133225. Then I find the distance of the planet, already known, 60, and cube it, which makes 216000. Now by a rule in arithmetic, I find out a certain number which will bear the same proportion to this, that the squares 729, and 133225 bear to each other; that proportional number is 39460356, and the cube root of this last number, which is 340, will express the distance of the sun from the earth, which was what I wanted to know, so that the earth is distant from the sun, 340 of its own semi-diameters.

THIS law, of such great benefit in astronomy, was found out by *Kepler*, but far from being able to give the cause of it, which the reader has already seen; as we have taken it from *Newton* and the Marquis *de l'Hopital*. *Kepler* supposed that the sun was possessed of a kind of

vegetating soul, and that turning round itself it attracted the planets, and that the planets would actually fall upon its surface, but that by turning upon their own centers, (as we see a top) they by this means resisted the sun's attracting power.

THE laws we have hitherto laid down suppose that all the planets move in circles; but in truth this is not the case, for while they are attracted by the bodies respectively in their centers, at the same time they are in a lesser proportion attracted by each other. For this reason they do not move in circular orbits, but in such as are elliptical, of the figure A in the plate, the diameter of which is greater one way than another. (Fig. 10.)

By this we see, that though the universe may be resembled to a nice machine, in which all parts are wisely adjusted, yet the constant and paternal inspection of the great Architect is ever requisite,

requisite, his regulating hand is always over all his works, and should he leave them but for a time, their order and regularity would be at an end. The planets would necessarily disturb each others motions, and when several of them came to the same quarter of the heavens, they would attract the sun with united influence, and perhaps at once destroy the common regulator of their motions. In this manner the uniformity of nature would be destroyed, and as it could never repair its own breaches, the whole system would run into endless confusion. Of this disturbance we had a remarkable instance in the comet which lately appeared; which, in receding from the sun, went so near the planet *Jupiter*, as to be greatly affected by its attraction. But a solicitude for the disarrangement of the universe, belongs only to him who is above all concern.

CHAP. IX.

*Of the Figure of the Earth, and the
different Weights of Bodies upon its
Surface.*

EXPERIMENTAL Philosophy is not, at first sight, so pleasing as that amusing science which is formed upon conjecture; but it improves as it proceeds, and the mind, by first more painfully measuring the effects of bodies upon each other, at last comes to arrive at the causes. We have seen how by means of the attraction of bodies upon each other, all nature seems to put on uniformity; but this power makes the heavenly bodies not only move in circles round a distant center, but also regulates the motion of the earth upon itself. For the earth, moon, and planets have two motions, as we see sometimes when boys are whipping a top, which, while it is spinning upon itself, is at the same time going round a circle chalked on the floor.

THIS

THIS motion which the earth has upon itself, is that which causes day and night, as either side is turned toward, or from the sun. Now while the earth is thus whirling round, that part upon its surface will have the greatest swiftmess, which is most distant from its center of motion. As for example, a body placed upon the circumference of a chariot wheel, while it is turning, will have twenty times the motion of a body placed upon the nave. A body, if placed upon the equator of the earth, is like this body at the circumference of the wheel, while another at either of the poles, is like one placed upon the nave. Now this body placed at the equator, it is evident, would fly off, by reason of the earth's centrifugal force, with great velocity, were it not held to the earth by the infinitely stronger power of attraction. However, though it still holds to the earth by its gravity, yet by its centrifugal force, it in fact loses a part of its tendency to the earth, and is diminished therefore in a part of its weight.

weight. Thus if weighed at the equator, a body is sensibly lighter than the same when weighed at either of the poles, and this has often been measured, by the means of pendulums, in a method which shall hereafter be seen. Let it suffice here to observe, that a body, which at *Paris* would weigh two hundred and twenty pounds, would at the equator only weigh two hundred and nineteen.

SUCH is the difference of gravity on different parts of our globe; from whence it appears, that bodies placed at the equator, have a greater tendency to fly off from the surface of the earth, than such as are placed at either of the poles. Now, if instead of bodies flying off at the surface of the earth, we should suppose the parts of the earth itself were moveable among each other, and the whole, for instance, composed of a great heap of running sand; then it is obvious, that while the earth turned round its axis, her parts would attempt most to fly off where

where the motion was greatest; it would swell under the equator, for the greatest quantity of materials would run to that part.

WHAT is said here of the earth's swelling at the equator, is actually found to be true; for though we often call it a globe, yet it is by no means perfectly round, but widened out at the equator, and flatted at both poles, like a turnip; or, if the learner is fonder of a hard name, its figure may be called an oblate spheroid. Astronomers and natural philosophers had long been of a different opinion with regard to the figure of the earth; the *French* and *Italian* geographers universally considered it as a spheroid rather lengthened than flatted, rather like an egg, than the figure mentioned before. *Huygens* and *Newton* however, persisted in affirming the contrary. The dispute continued long, but was at length determined, highly to the honour of the latter; several members
of

of the academy of sciences having been sent, in 1735, to the polar circle, and others to *Quito*, for the purposes of determining the figure of the earth; they concurred in affirming with *Newton*, that the earth was flatted at the poles. Nor was this a small conquest gained in favour of the *English* philosopher's system. For it must be observed, that if the earth's figure were proved not to be flat, a part of his doctrine of gravity would be false. For it seems the earth has yet another motion; its poles are found to point slowly, to different parts of the heavens, in a series of years, like a top going to fall, which while it spins round itself, nods also, with a sort of circular motion. Of this nutation of the poles, which it is not our business here to examine, he had shewed that gravity must be the cause, provided the earth were flat, which he believed it was.

BUT though the earth is allowed by the generality of modern philosophers to

be an oblate spheroid, yet some latter observations have induced many of them, and those among the foremost, to think it of a more irregular figure. Of this opinion, we find *Buffon*, *Condamine*, *Maupertuis*, and *Boscovich*. The principal reason upon which this opinion is founded, is, that a degree just measured on the meridian of the globe in *Italy*, by *Boscovich*, was found to differ from that measured in *France* in the same latitude, 70 *French* toises. Could we be certain that the admeasurements of these two different meridians were made without error, this would, undoubtedly, be a demonstrative proof of the irregularity of the earth's figure. But an error of two seconds will produce the difference now complained of; and where is the observer that can answer for two seconds? The opinion therefore, of the earth's oblate figure still remains uppermost, yet not with such entire conviction, as before this last admeasurement was made.

CHAP. X.

*Of the Descent of Bodies to the Surface
of the Earth.*

THUS far we have shewn the general cause why bodies fall to the earth, and proved that the force of gravity which draws them down becomes less, as the distance, when squared, becomes greater: That a body, which at one semi-diameter of the earth, weighs one pound, will have four times less weight at two semi-diameters, and nine times less at three. This difference in weight, we said, might be sensible at great distances, but not at any distance we can remove from the earth's surface; for though we could remove a mile above the earth, and weigh a body there, yet this encreased distance would take but little from its gravity, for a body on the surface of the earth, is already removed four thousand miles from the center of the earth, by which it is attracted; and
removing

removing it one mile more will be but making a decrease of one mile's attraction from four thousand, a difference too minute for sense to discern. This decrease of gravity, therefore, as we remove from the earth, is only an object of the imagination, or if we have any sensible proofs, they are obtained by measuring the heavenly bodies around us.

IT suffices us therefore to know that bodies, though to sense they have not more gravity in the lowest pit than upon the highest mountain, in general fall by that power. But the cause why bodies fall with greater force as they fall from higher places, which we shall now see to be another law of falling bodies, is founded upon quite other principles, discovered long before the principle of gravity was thought of.

THE most unlettered rustic is sensible, that the fall of a stone is to be dreaded in proportion to the height from whence
it

it descends; that if it falls from a place a foot above his head, it is not so likely to be fatal, as if it fell from the house-top. From this it is obvious, that the body thus falling, acquires new swiftness the longer it falls; and in fact, it has been found by trial, that a leaden bullet, let fall from the top of the steeple in *Westminster Abby*, acquired such velocity towards the end of the fall, that it pierced through a deal board that was fixed beneath.

THE exact quantity of swiftness, which a body thus falling acquires, was first demonstrated by *Galileo*, and his experiments confirmed by *Grimaldi* and *Riccioli*, who, by letting heavy bodies fall from high towers, and then by computing the time in which they fell, and the heights of the towers they fell from, determined the quantity of swiftness gained in every instant of the fall. In determining these laws however, they suppose that the bodies were free from that resistance in their

their fall, which they receive from the air through which they move, and which resists the falling body with greater force, the quicker the body descends; as when walking we feel the wind stronger when we go fast than when we move slow.

BUT though, as was said, this swiftness, which descending bodies acquire, is obvious to common experience; the exact quantity, thus acquired, is not so easy to be determined. In order to find this out, we must consider that as a body descends, the power of gravity is constantly and uniformly increasing its swiftness; the impression gravity gives it in the first instant of its fall, would alone be sufficient to make it descend, though it received no new impression; (as a stone, impressed by the hand, moves still forward, after the moving cause ceases to act) but gravity still operates upon it, and a new impression is added in the second instant of the fall, which conspires with the first impression, and doubles it;
and

and in the third instant, the body goes on with the double impression, and receives also a new one which triples it; so that we may suppose every body falling, to receive a new impression every moment of the fall, and that the velocity increases as the moments increase.

Now then let us imagine a bullet dropped from the tower of *Westminster Abby*, and that in the time of one second it falls the space of one pole (sixteen feet and an half,) its velocity is still increasing; at the end of this fall it will have acquired as much swiftness as in the next second would have carried it two poles, or double the former, although no new impression from gravity were added; but a new impression being added, will make it fall through three poles. As the velocity is increased towards the end of every fall, in the beginning of the third second, it will have acquired as much velocity as would have carried it through four poles, and the

the uniform impression from gravity being added, will make the body fall through a space of five poles. At the beginning of the fourth second, it will have acquired as much velocity as would have carried it through a space of six poles, and one, which is the uniform impression, being added, will make the body fall through a space of seven poles. At the beginning of the fifth second, it will have as much velocity as would have carried it through eight poles, and the new impression being added, will make it fall through nine poles. Thus in the first second, it will fall through 1 pole, in the next 3, in the third 5, in the fourth 7, in the fifth 9 poles. All these being added together, make 25 poles, or 300 feet; so that if the tower be 300 feet high, the bullet will fall from its top, in about five seconds. And the velocity it will have acquired in the last second of the fall, will be five times greater than that which it had in the first. Thus the velocities, like the times, in-

crease uniformly, 1, 2, 3, 4, 5, but the spaces, through which the body falls, taken separately and in order, increase by odd numbers, 1, 3, 5, 7, 9, &c.

To prove all this by experiment: *AB*, and *CD*, (fig. 11.) are cords made of the best catgut about twelve feet long, tightly extended, parallel to each other, at some inches distance, and making an angle of about $22\frac{1}{2}$ with the surface of the earth. *G* is a weight which slides very freely, by means of two pulleys, along the cord *AB*, and its weight is so contrived to fall below, that its upper part always retains the same situation. *H* is a pendulum of a moderate weight which moves upon two pivots *Aa*, and its rod is lengthened a little towards *f*. The length of the pendulum ought to be such as to vibrate once, while the weight *G*, runs through the ninth part of the cord *AB*. To measure this exactly, the cord should be carefully marked out into nine equal parts, and upon the other
parallel

parallel cord, and just opposite the first mark, is to be fixed the little bell K, which, by means of a screw, can be placed at any part of the cord at pleasure; this must also have a little clapper, which the weight G, as it runs down its own cord, may strike against. On the other hand, the pendulum H also strikes a bell of a different tone, and the tail of the pendulum rod that is lengthened to *f*, cuts as it passes a small silk thread, that holds the weight G from sliding. In this manner the whole being well adjusted, the weight G no sooner begins to move, than the pendulum strikes its bell I for the first time, while the other bell K gives its sound, just as the bell I gives its second alarm. Thus between the first and second sound of the bell I, there intervenes a time, of which we have the exact measure, and also we have a measure for the space the weight slides. We then screw the bell K to that place of the cord where the weight G shall make the second sound of the bell K, answer the third

of the bell I, and thus of the rest; so that we may thus measure the spaces run through, with the times of the descent. It will by this appear, that during the first vibration of the pendulum, the weight G shall run over a ninth part of the cord; if it continues to move forward during the second vibration, it will arrive at 3, and in the third vibration at 5, in the fourth at 7, in the fifth at 9; so that the spaces taken separately, go on increasing by odd numbers.

By these means, if a body is let fall from a tower, and if we know the time of its falling, we are enabled to tell what velocity it has acquired in every moment of its descent, what space it has run through in each part of time taken separately, and how much these spaces make when added together; or in other words, how high the tower is, from whence the body falls.

YET

YET this height may be estimated by an easier method. For it is plain that the longer the time the body has taken to fall, and the greater the velocity with which it moves, the greater must be the height from which it falls: now then we may multiply the time of the fall by the velocity, and the product will give us the height or space through which the body has fallen. Thus if the time a bullet has taken to fall from the top of *Westminster* tower be 5 seconds, and the velocity it has acquired (which is always increasing as the time) be 5 times greater than in the beginning, if the bullet fell 1 pole in 1 second, (which all bodies by the force of gravity nearly do) then at the end of 5 seconds, it would have fallen 5 multiplied by 5, that is 25 poles, or 300 feet, the height of the tower.

IT was said that the times and the velocities are always equal: as that is the case, it will be more expeditious still, to

multiply the time of the bullet's fall, by the time itself, that is, square its number, and the product will give the space through which the bullet has fallen, as exactly as if the time were multiplied by the velocity. We may therefore conclude universally, that the whole of the spaces described by a falling body, is as the squares of the times, or the square of the velocities, it is indifferent which,

LET us only add one position more on this difficult subject, and we have done with its intricacies. From all that has been said, it will follow, that the velocity acquired by an uniformly accelerated body at the end of the fall is such, as if it continued to move forward with that velocity, without any new acceleration, it would, in an equal time, move through a space double that of the fall. For the space it would describe, supposing it went on with an accelerated motion, would be, as we proved before, as the times multiplied by the velocities; so that

that by this it would have moved through three times as much space at the end of its continued motion, as it did at the end of the fall. But in the present case, though the time increases, the velocity does not increase, so that we are to multiply the whole time of the body's motion, by that part of the velocity only, which it had at the end of the fall, and the product will be the space described by the unaccelerated motion continued after the fall, and it will be found just double the space described in the fall.

As the motion of bodies falling from a state of rest, is uniformly accelerated, so likewise the motion of bodies thrown upward is uniformly retarded; for the same force of gravity which conspires with the motion of descending bodies, acts in direct opposition to such as ascend, retarding those that rise, as much as it accelerates those that fall. If therefore, I should desire to throw a bullet up to the top of the tower in *Westminster*, I must give it as much velocity with my hand to

make it rise, as it would acquire by the force of gravity if it fell from that height. The action of gravity is constant and uniform, and in whatever time it generates any velocity in a falling body, in the same time must it destroy that velocity in a rising body.

THESE are the celebrated discoveries of *Huygens*, and have been employed to very useful purposes, in several of the practical parts of mechanisim. They serve also to explain many of the phænomena of meteors. A hailstone falling from the clouds, if uninterrupted in its descent, would strike us with more than the force of swan shot from a gun. But in proportion as the rapidity of its descent is increased, the resistance it meets with from the air is increased also; so that at last, the acquired velocity and the increased resistance come to act with equal power; after which, the descending body can fall no faster, but continues the same uniform progress till it comes to the ground.

C H A P. XI.

*Of Bodies descending down inclined Planes,
and of Pendulums.*

HAVING explained the descent of bodies falling freely by the force of gravity, it will be easy to estimate the force with which they will descend down an inclined plane, (fig. 12.) in which the direction of the fall is altered, but the absolute weight remains the same.

WHEN a body is withheld from obeying the impulse of gravity which always acts upon it, it is evident that it is prevented by some obstacle which resists its natural tendency to descend. For all bodies endeavour to fall by the shortest course, that is to say, perpendicularly to the earth. When bodies therefore fall down inclined planes, we must regard them as obeying the usual laws of gravity, as descending with an uniformly accelerated motion, but acted upon by

new forces, only taking up so much more time to descend, as the space is lengthened, over which they are obliged to fall. The more the space is increased, that is, the longer the inclined plane is, the more time will the body take in travelling it down. Thus suppose the inclined plane to be twice as long as its perpendicular height, then the body will be twice as long in falling, as it would if it fell from its top perpendicularly.

To shew this by an experiment; let us dispose the cords of (fig. 13.) in such a manner, as that they shall form an inclined plane A B, which is twice as long as it is high, and then let the pendulum be so adjusted, that while an ivory ball is falling from A to P, it may make one vibration. If the weight G begins to slide the same instant the ball is let to fall perpendicularly, it will not arrive at B till the end of the second vibration, which shews that the time of its descent is

is to that of the ivory ball, as the length of the inclined plane is to its height; and if the inclined plane were three times as long, its fall would be thrice as slow.

As the time of a body's fall is thus lengthened, in moving down an inclined plane, so also will its velocity be diminished; for that quantity of force which the body has received from gravity to make it fall a certain perpendicular height, is here employed in making it describe a space, which, by the experiment, is twice the length of the perpendicular; therefore the body will move but with half the force that it would down the perpendicular, and consequently, with but half the velocity. As the time of a body's fall is thus lengthened in proportion to the inclination of the plane, we must now go on to observe, that a body will take as much time in falling obliquely down the short cord of a circle *MN*, as it would in falling
less

less obliquely down the longer cord M L, or in falling perpendicularly through the diameter M P. I repeat it, *that a body will take as much time to fall down the shorter cord of a circle, as the longest.*

For bodies falling down the cord of a circle, may be considered as moving down inclined planes, as A B, A C; but all bodies moving down an inclined plane are, as we observed, actuated by two forces; and all bodies thus actuated, move in the diagonals of a square or parallelogram. But all the diagonals thus described, by the united action of two forces, are always performed in equal times, and therefore all the cords of a circle are so too. Thus for instance, the body takes no longer time in moving down the cord A B than it does down the cord A C, for both are diagonals described by two forces that continue the same.

BUT though velocity is diminished down an inclined plane, yet if
two

two bodies fall from equal heights, the one perpendicularly, the other down the most inclined plane whatsoever, the velocity acquired at the end of the fall in both will be the same. For as gravity is the same in both, and is alike uniformly accelerated in either, all the increments of velocity either body receives during the fall, will be summed up in each at the end; but those increments are equal, as they are produced by the same cause, which is gravity, and therefore the velocities at the end will be equal.

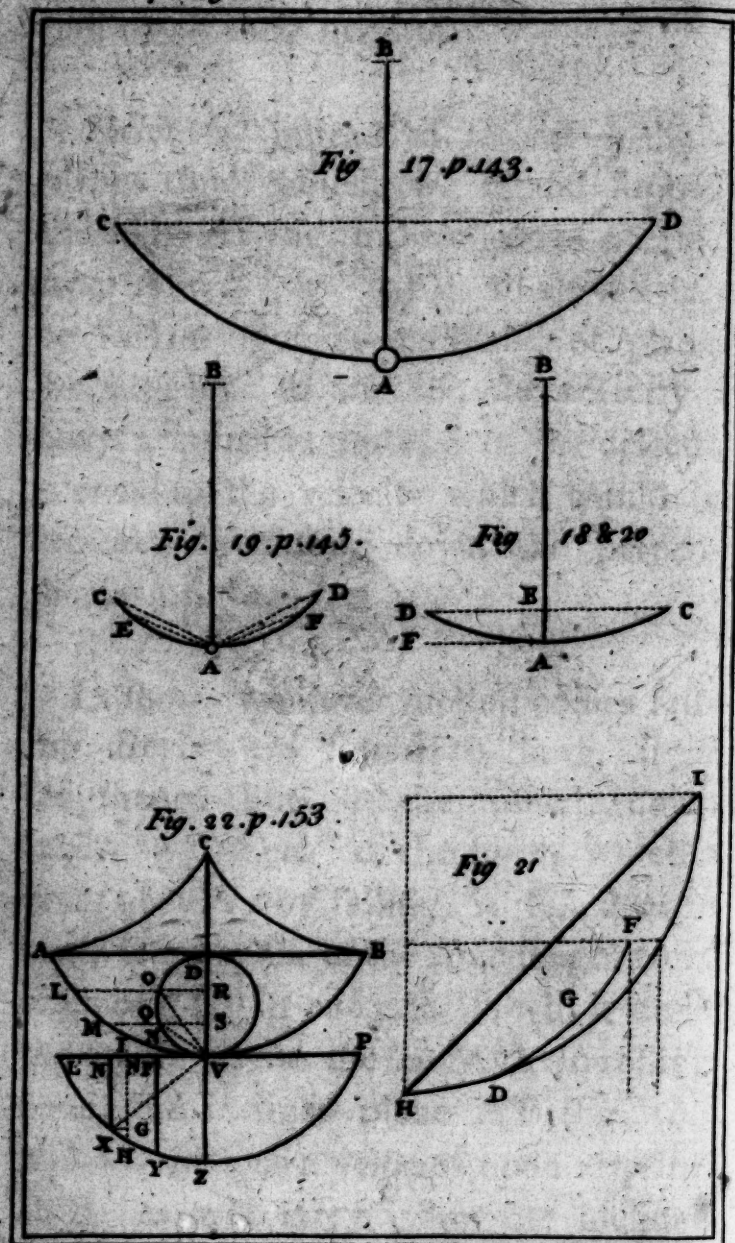
If, instead of one inclined plane, we should suppose several united (fig. 14.) and the body moving down them one after the other, its velocity, at the end of the last plane, will be as great as it would if it fell perpendicularly from the top of the highest plane. For the velocity the body acquires at the bottom of each of these planes singly, is in proportion to its respective height, and consequently the sum of the velocities of all
taken

taken together, is in proportion to the sum of all their heights.

Now if, instead of several inclined planes thus united, we should suppose the body moving in the curve of a circle, from A to B (fig. 15.) as all curves may be looked upon as a number of planes inclining one to another, the velocity a body acquires at the end of the descent, is equal to the velocity which would be acquired by falling down the perpendicular height.

IN short, whatever motion bodies falling freely are found to have, it is lengthened, but not diminished, down inclining planes. If the force, which a body acquires by falling, is sufficient to carry it up again to the same height from whence it fell in one case, so will it be in the other. Thus the body D, in rolling down the inclined plane AB (fig. 16.) will acquire such a velocity upon arriving at B, as will carry it up the inclined





Proudest

plane BC almost to C, and would carry it quite up, if the body and plane were perfectly smooth, and the air gave no resistance. And likewise the velocity of a body falling down the curve of any circle, (fig. 17.) as from C to A, will make it rise from A to D; and universally, in whatever direction a body falls, it will, if unrestrained, rise to the same heights from whence it fell.

FROM hence we may therefore lay it down, that if, by any contrivance, a body is made to descend through the arch of a circle, as from C and A, (fig. 18.) and with the velocity acquired by the descent, to ascend along the arch AD of the same circle; the arch AD which it describes in its ascent, will be equal to the arch CA described in the descent, and the times in which those arches are described will be equal; and this is the case of the pendulum, which is an heavy body, as A, hanging by a small cord or wire BA, and moveable about the point

point B; the weight being raised as high as C and thence let fall, it descends by its own gravity to A, and then ascends by its acquired velocity to D, where, losing all velocity, it will be turned back by its gravity, and descending through the arch DA will, upon its arrival at A, acquire the same velocity as before, with which it will ascend to C; and thus it will continue, and if uninterrupted by external obstacles, would for ever continue a vibratory and equal motion.

THIS is that well known instrument in common use for measuring of time, as nothing yet found out divides it into portions so exactly equal; nor does the inequality of the arches, it may be made to describe, make an inequality in the time of the vibration. For the vibrations of the same pendulum are performed very nearly in equal times; let it swing never so violently, or move never so feebly, yet it performs both in equal times. We have already proved that all the cords
of

of a circle are described in equal times, and if the cords are thus described, so will small arches, which may be considered as little differing from their respective cords. Thus if a body (fig. 19.) be as long a time falling down the dotted cord EA, as it is falling the longer dotted cord CA, so will it be as long falling in the circle from E to A as it is from C to A; the long and the short arch will be fallen through in the same time, and they also rise on the opposite side towards D, in the same proportion.

THE disproportion in the length of two pendulums it is, which creates the great difference of time in their vibrations; the longer the pendulum the slower are its vibrations. The cord of any pendulum is to be considered as proportionable to the diameter of a circle, which the weight at the end describes; therefore, if a body is let fall from the top of this diameter as B, (fig. 20.) and if it takes a second in falling, it will continue a similar

time, as we have shewn, in half its vibration C A, and another second to complete its vibration in rising up to A D; now if we should lengthen the pendulum, we should lengthen the diameter of the circle, and as consequently the body will be a longer time falling down a longer diameter than a short one, so will it be a longer time in describing its respective arches.

As I know that the time of half a vibration is equal to that of a body falling down the diameter of its respective circle; if now I would desire to know, from what height an accelerated body would fall, during the time of one complete vibration, the solution is easy. For as the two half vibrations are exactly equal, supposing in the first half vibration the body fell a space of sixteen feet, in the second half vibration, if the body moved equally, it would describe a space exactly equal; but the spaces described by falling bodies are increased by odd numbers,

1, 3, 5, and 7, so that the body will describe 3 times sixteen, that is 48 feet, which added to 16, makes 64 feet, the whole time of the fall during one complete vibration.

SUCH are the most important properties of the pendulum, an instrument which has been converted to the most useful purposes, either in measuring time, and in scientific affairs in giving its nicer divisions. By this instrument also, we can measure the distance of a ship, by measuring the interval between the fire and the sound of the gun; we can also measure the distance of a cloud by numbering the seconds between the lightening and the thunder; but in both these last cases we must know the exact time the sound takes in travelling through a certain space, which we shall hereafter explain. *Galileo* had no sooner found out these properties in the pendulum, than he turned them to the advantage of philosophy; by those he measured, with

some exactness, his astronomical observations, and the pleasure thus resulting from their use, in some measure, recompensed the pain of investigating their properties. However, the pendulum he made use of could only measure time, for he had no instrument like our clock, which might sum up its vibrations. It was rather, in his hands, the instrument of a philosopher, than a thing that could be rendered universally useful.

WHAT was begun by *Galileo* was, in some measure, improved by the industry of *Huygens*, a man who added the acutest penetration to the most indefatigable industry. It was he, who made use of them in regulating the movement of clocks; and this happy combination has since been universally adopted. To have an idea of the manner in which a pendulum regulates the motions of a clock, it is to be observed, that all clocks are put into motion either by weights or springs: but the wheels, if guided by these

these alone, would never turn equably, therefore the pendulum has two palates, as they are called, which at equal intervals rise and fall, and let the teeth of the wheels pass under them in equable succession, so that the time is marked with great exactness. But this succession is, undoubtedly, the nearest an equality of any thing we yet know of; however, there are some causes which destroy the regularity of the motion in all clocks. We said, that all equal pendulums, vibrating in small arches, are performed in times nearly equal; however, we must now observe, that these times are not entirely so, for those which describe the greatest space, are longest in performing it. This difference of time indeed, is not immediately perceivable by the senses, and in short durations may be neglected; but in a succession of vibrations summed up together, it may come to a considerable amount. In fact, it has been found by experience, that the best regulated pendulum clocks, wherein the

greatest care has been taken to make the pendulums vibrate in equal arches, have notwithstanding varied in a course of time, so as to stand in need of a new regulation. And it is almost impossible to make the pendulum constantly describe similar circular arches, and consequently to make its vibrations precisely equal; for if the wheels, on account of the thickening of the oil by frosty weather, or any other cause, grow more sluggish, this will diminish also the swing of the pendulum, and therefore the length of its arches, and consequently the portions of time that it is made to measure, so that the clock goes too fast. On the contrary, when the oil is thinned by heat, and the wheels thus grow more slippery, or from their constant friction become more smooth, so as more freely to obey to the moving power, the pendulum will of course be acted upon more forcibly, and caused to vibrate in larger arches, by which means, the time of each swing is enlarged, and of course the clock goes too slow,

flow. This source of inequality did not escape the penetration of *Huygens*: to remedy these inconveniences, he thought of another method of adapting pendulums to clocks, in which it would be absolutely indifferent whether the pendulum moved in larger or smaller arches; he found that if they vibrated between two curves of a geometrical figure, called a cycloid, the irregularities arising from the alterations upon the pendulum, could produce no irregularity in the vibration.

A CYCLOID is a figure described by the revolution of a point in a circle, while that circle is rolling upon an even plane. Thus a nail in a chariot wheel describes cycloids as the chariot moves along. *Huygens* demonstrated, that however unequal the arches were, which a body falling in this curve might describe, they would all be performed in equal times; for the nature of this curve is such, that a body falling down it acquires by velocity in the beginning,

more than it loses in time at the end. To explain this, let us suppose the fourth part of a circle AED (fig. 21.) divided into four parts by right lines, and a body falling down them, as down so many inclined planes. If the velocity were not accelerated, it is evident that the body would be a much shorter time in rolling almost perpendicularly from A to B, than obliquely from C to D. But the body goes with an accelerated motion, and while it goes from C to D, though the plane be most inclined, yet it performs it with the velocity which it has acquired by falling from A to C. Now it is evident, that if the planes A, B, E, were more perpendicular, the velocity through CD would be greater. The line FGH, which is the curve of a cycloid, is just such a figure; the upper part of its curve FGD is more perpendicular than the arch of the circle IED, as is obvious to the eye; and therefore the velocity acquired by the body at D, will be greater by falling from the cycloid F, than

than if it fell from the curve I. Nay what is more extraordinary, by the same reasons, the time in which the body falls from F to H, will be less than if it fell down the right line IH, though it is evidently the shortest way. Upon this was founded the famous problem which *Bernouilli* proposed to the geometricians of *Europe*. He demanded in what line a body, falling obliquely, would fall soonest to the earth? This was not a right line, though the shortest that could be drawn, but the curve of a cycloid, which was afterwards called by the hard name of a Brachystochrone, or the line of quickest descent.

IT was between two of these curves that *Huygens* suspended a pendulum, as between the curve of the cycloid CA and the curve FB, (fig. 22.) might be suspended the pendulum CV, in such a manner, that the strings which hold the pendulum, as often as it moves from the perpendicular towards either side, might
bend

bend round either curve, and by this also the pendulum would describe another curve of a cycloid AVB. By these means he supposed that the curve AVB being similar to the other two curves, would describe all its vibrations in equal times, and thus communicate a perfect regularity in clocks. However, experience and theory have evinced the contrary.

WHAT seems most remarkable in the error of *Huygens* is, that the learned of *Europe* persisted in the error for more than thirty years, notwithstanding the irregularities that this produced in the movements of clocks. One while they attributed it to the inaccuracy or ignorance of the artist; another time to the obstruction of some physical causes; Mr. *Sully* was the first who undeceived them. He shewed that the regularity of cycloidal pendulums was obstructed upon a very sufficient account; namely, the flexibility of the rod or string of the pendulum, which
it

it must have had to bend along the curve on either side, and which altered the weight of the pendulum upon the work to be regulated. Another sufficient reason against cycloidal pendulums is, the moisture which the silken strings imbibe from the air; whereas in other pendulums a steel rod is made use of, which is not subject to equal variations. In short, these kind of pendulums are now entirely out of use; however, it is possible they may again be brought into fashion, since a late improvement in one of the movements of a clock by *Le Roy*, in which the cycloidal pendulum may be used with advantage.

SUCH are the assistances which geometricians have brought to regulate the vibration of pendulums, and to make all the arches they describe equal; but there are other natural causes of irregularity, which are entirely irremediable by calculation. As the rod of the pendulum, like all other bodies, contracts with cold, and dilates
with

with heat; so it must in cold weather be considerably shorter than in hot weather, and consequently its vibrations must be swifter in winter when it is coldest than in the heats of summer. It was a suspicion of this kind that induced some to think, that as the pendulum at the equator was found to move much slower than the same pendulum towards the poles, this might proceed from its being lengthened by the heat of the climate. In this however they were deceived, for its slowness there (as we observed before) proceeds from its having a greater centrifugal force, which thus makes the force of gravity less at the equator, than towards the poles. I say, they were deceived in this; for it has appeared by the most careful experiments, that the lengthening of the pendulum in the hottest weather, bears no sort of proportion to the slowness with which the pendulum at the equator is found to move. Mr. *Mairan*'s pendulum at *Paris* required to be 3 *French* feet, 8 lines and an half, to vibrate seconds. This pendulum,

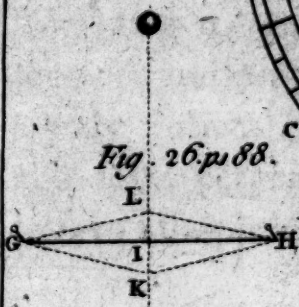
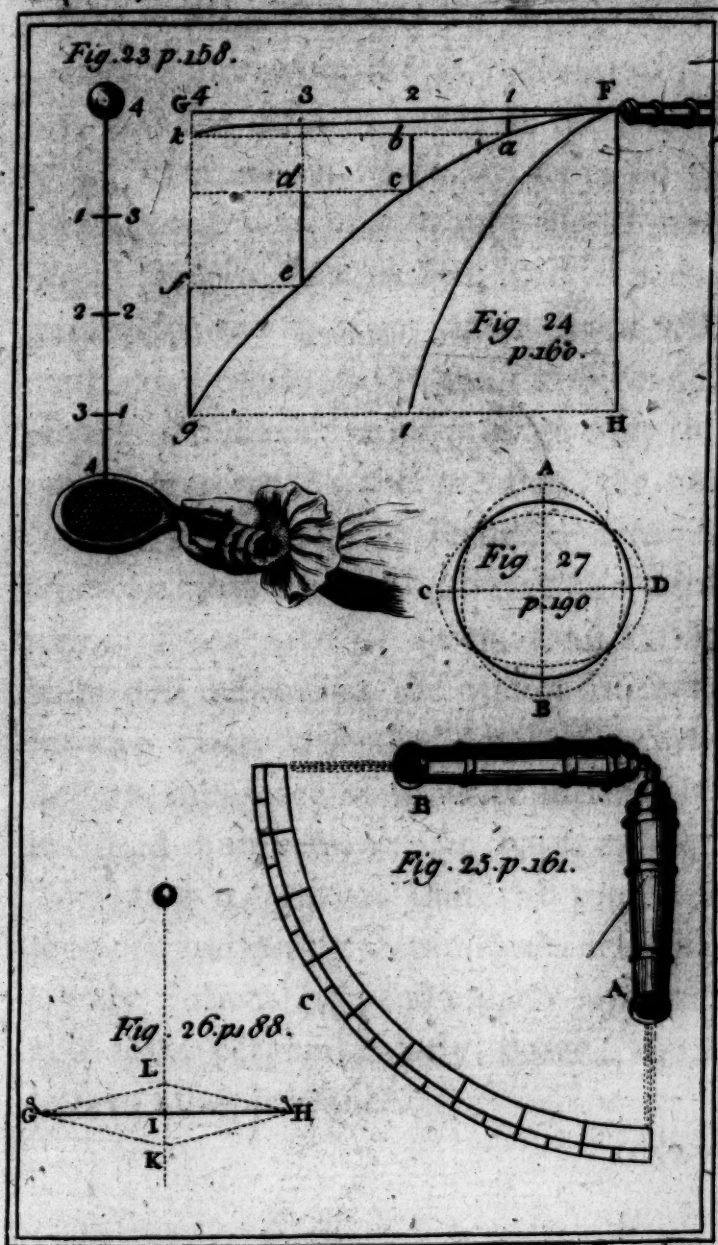
lum, by every experiment that has been tried to make it vibrate seconds at the equator, must be 2 lines shorter. Now if the air at *Paris* were as hot as boiling water, yet it could not require the pendulum to be made the third of a line shorter, so that the heat at the equator is not the only reason that makes it too long to vibrate seconds there, since the heat alone could not increase its length above a third part of what we find it.

THE lengthening of the rod of a pendulum by heat, and its contraction by cold, are inconveniences however which some mechanics have attempted to obviate, by employing another piece of metal in the movements of the machine, which shall counteract the lengthening or shortening of the pendulum, by its own dilatation or contraction. Mr. *Harrison's* machine is made upon this principle, *Le Roy* and *Cassini* have published treatises upon this subject: it is our duty in so ample a subject, to excite curiosity rather than to gratify it.

C H A P. XII.

Of Projectiles, or that Motion caused by a single Impulse, and at last destroyed by Gravity.

ANY body thrown off, either from the hand, or shot forward by the force of powder or any other means, is called a projectile. Thus a stone driven from the hand, a ball driven from the mouth of a cannon, are called projectiles, from their being projected or cast forward. When the blow of a racquet, (fig. 23.) or any other impulse, determines a ball to ascend perpendicularly, it impresses a force directly contrary to the gravity of the ball; so that the ball will rise with a motion, equal to the superiority which the impelling force has over gravity. Thus if the impelling force is capable of driving the body at the rate of 60 feet high in one second, as the force of gravity draws it and all bodies back to the earth about 16 feet





in the same time; the height to which the ball will rise in the first second, will be but 44 feet. In the next second of its ascent, as the power of gravity still operates upon it, and as the spaces it describes increasing are as odd numbers, it will make it fall 3 times more, which is 48 feet, which subducted from 60 in this second, which it would rise if uninterrupted in this second, will leave it but twelve feet to rise. After this it will cease to ascend; for in the third second, gravity will have the advantage over the projectile force of the racquet, for the racquet gives only 60 feet in a second, whereas gravity would give at the third second 5 times its first force, that is, the body will descend at the rate of 80 feet; for the spaces described by bodies falling by the force of gravity increase by the odd numbers, 1, 3, 5, 7, 9, &c. from this it appears that the projectile force is uniformly diminished, and that a body thrown perpendicularly upwards also falls perpendicularly down, or at least to all appearance.

Now

Now instead of throwing the body perpendicularly upward, let us suppose it to be shot directly forward, and still supposing the force to go uniformly forward, let us divide the whole of its way FG (Fig. 24.) into four equal parts. If the ball F , during the first second, falls $1 a$ by its force of gravity, during the next second, the cause increasing by odd numbers, will make it fall 3 times as low, to $2 c$; in the third second it will fall 5 times as much, to $3 e$, and in the fourth second it will fall 7 times as much, to $4 g$. By this means we shall have a succession of points, $F a c e g$, which together form a curve, which geometricians call a *Parabola*. And in this curve all projected bodies will move, in whatever direction they are thrown, except directly upward, or perpendicularly downward.

Now should it be asked in what manner a cannon should be planted in order to drive a ball to the greatest possible distance, the

the solution will be obvious. For if we suppose it raised perpendicularly as B, (fig. 25.) it is evident that the ball shot from its mouth will fall perpendicularly back again, to the same spot from whence it was driven. And if we suppose the cannon laid level with the surface of the earth at A, it is evident that the ball can be shot to but a very short distance; for as it describes the curve of a parabola, and consequently is every moment descending, strictly speaking, it would reach the ground the moment of the explosion. To give therefore a ball the greatest amplitude, and to drive it to the greatest random distance, we must point the cannon exactly between the horizontal direction A, and the perpendicular direction B; that is, we must elevate it to about forty five degrees of a circle, or the half of its quadrant C; and every day's experience in gunnery confirms the truth of this theory.

ALL the *Ballistic* art, or that part of engineering which consists in measuring

with exactness the force of a cannon ball, or a bomb, and such like, consists in a due knowledge of the weight of the body to be driven, and the projectile force that drives it. The weight of the body is easily measured; the force of the powder requires much more assiduity to understand, and can after all be only found by experience. Upon understanding the quality of this, and the quantity that can be employed with effect, depends almost the whole of the gunner's art. I say, that can be employed with effect; for only a certain quantity of the powder is always consumed, which is put into the piece; the rest is discharged entire without ever taking fire, or at most is not kindled till the ball is past the sphere of its force.

EXPERIENCE, therefore, is the best guide in the doctrine of either throwing bombs or shooting balls; for the theory, of which we have given here but a small part, can carry the young engineer but
a short

a short way, and indeed it is clogged with so many exceptions, that it is rather an object of amusement than utility. For first, the resistance of the air considerably alters the former calculations. Mr. *Robins*, who some years since published a work entitled *New Principles of Gunnery*, even asserts that the figure the body describes is not a parabola; others, later than him, who appeal to experience as well as he, affirm the contrary. Future experiments must determine the dispute; for in natural things, the experimenter should ever lead the geometrician *. What we have here said with respect to the projection of bodies, and of their describing parabolas, must be considered as their motion is seen by us situated on the earth; but by a spectator, removed at a distance from its surface, and not par-

* They who are desirous of having a more Geometrical knowledge of this subject, may consult an excellent treatise, entitled *Balistica Arithmetica*, by Mr. *Maupertuis*, which in two pages contains more than volumes on the same subject written by some others.

taking of its motion, bodies thrown forward would be seen to describe very different curves from what an inhabitant of the earth conceives. For in reality, a body thrown upward, beside the two forces already mentioned, is urged also by the rotation of the earth upon its axis. Some say, a body thrown upwards will, to such a spectator, appear to describe the curve of a parabola as before; others are for restricting this assertion. Happily for mankind, and for philosophy too, the question is merely speculative: the figure is very difficult to determine, but it is easy to determine that all enquiry is to be discontinued where it ceases to be useful.

C H A P. XIII.

Of the Communication of Motion.

NATURAL philosophy, strictly speaking, is little else but the measuring of such motions as are obvious, or accounting for such as proceed from an hidden cause. We have already accounted for and measured the motions of bodies, that to the vulgar seem to put themselves into action, or, that put into action by us, go on without communicating their motion to any others: of the first sort, were bodies attracting each other; of the last were projected bodies, that were supposed to meet with no obstruction in their way.

WE now come to consider that motion, which is communicated from one body to another, without considering the first cause which gave that motion to either. If upon seeing two bodies in motion, I apply my strength to stop

M 3

either,

either, I will naturally and justly conclude that body to have had most force, which required most of my force to stop it. Now there are two things by which a body acquires this superior force; it either moves very swiftly, or the body moving is very heavy: in either case it requires very great force to stop it, but most of all, if it is at once both swift and heavy. A tennis ball, though it moves very swiftly, will give but a moderate blow; a leaden bullet, moving with equal swiftness, would be fatal. The force therefore, with which a body moves, is in proportion to its swiftness and weight: or, to express the same thing in harder words, the *momentum* (for so is the force usually called) is compounded of the quantity of matter in a body and velocity united. If then at any time we desire to know the force with which a body moves, it is but multiplying the velocity by the weight, or the weight by the velocity, and the product is the force sought for. So that by this we see that

two

two bodies may go on with very different degrees of swiftness, and yet both move with the very same force, provided the difference of their weights balances this excess. Thus, suppose a bomb to weigh 40 pounds, and to move 2 miles in a minute; and a cannon ball to weigh 4 pounds, and move 20 miles in the same time. If I would know which will strike down a parapet with greater force, I multiply 40 pounds, which is the weight of the bomb, by 2, which is its swiftness, and that makes its force 80. Then I do the same by the cannon ball, and 20 multiplied by 4, gives 80; so that the force in both is equal, and either would level the parapet with equal force. Once again therefore, I repeat it, that *the force or momentum of any moving body is found, by multiplying its velocity by its weight.*

To prove this another way: if it should be said that bodies, which move with equal swiftness, will also move with

M 4

equal

equal force; suppose I threw any body forward, and by the time it got to some distance it should divide into four different parts, these would still move to the end of the cast with as much swiftness as the body would if it had remained entire; but it would be absurd to say that these parts move each with as much force, since if so, the force in the four parts would be four times greater than what was at first impressed upon the body, so that to put it into motion, the effect would be greater than the cause.

ALL this is apparent, and was well known to *Archimedes*; but notwithstanding, obvious as it is, *Leibnitz* and his followers insist that the force of a body is to be estimated, not by multiplying the weight by the velocity, but by the squares of the velocity. Thus *Archimedes* would say, that a ball which weighs 2 and moves 2, would go on with a force 4; but *Leibnitz* contradicts him, and says that a ball which weighs
2 and

2 and moves 2, will go on with a force 2, multiplied by the square of the velocity 2, which is 8,

THE question in dispute therefore is, whether the force of a moving body becomes double or becomes quadruple, when the swiftness is only doubled? Now were the force employed in destroying its motion, allowed as a proper measure to estimate the force, with which the moving body went forward, the question would soon be at an end, and the followers of *Leibnitz* must submit; for to destroy the motion of any body whatsoever, we have only to oppose to it an equal weight to its own, multiplied by an equal velocity. Suppose a ball of 2 pounds moves forward with a swiftness of 2 yards in a minute; if I desire to stop it with another ball which weighs 2 pounds, this I can effectually perform if I give the last ball, which has already as much weight, as much swiftness as the former. This shews that if the
force

force destroyed in one body, be equal to that destroying in the other, the moving force must originally have been as the weights multiplied simply by the velocity, and not as the squares.

THE strength of this objection *Leibnitz* was aware of, and therefore answered it by making a distinction. The force sufficient, says he, in one body to destroy another body's motion, I grant, is rightly measured by the weight multiplied by the velocity; but the force with which a body surmounts obstacles, is to be estimated differently from that in which it is overcome by them. A body moving forward, becomes in a manner *animated* on its way, and when once put forward, overcomes obstacles that would have been insurmountable to its force at the very instant it began; as a man will overcome difficulties, when in his heat, that in his cool moments would be insurmountable. Suppose, for instance, a body, with a certain degree of

I weight

weight and swiftness, is able to coil up a watch spring; if I double the weight alone it will coil up but two watch springs, but if on the contrary I double the velocity alone, it will coil up four. Thus then, continues *Leibnitz*, we have two kinds of forces; dead forces, which are as the weight multiplied by the velocity; and animated forces, which are as the weight multiplied by the squares of the velocity. The dormant force which a body possesses while counteracted by some other, is the dead force; that of a body actually put into motion, the animated. An arrow drawn to the head and just starting from the bow, is a dead force withheld by the archer's hand, with a power that would, upon computation, appear to be equal to a certain weight multiplied by a certain velocity; but when the arrow is once shot forward, then the animated force begins, and with a power, made up of the arrow's weight and the square of its velocity. Whatever totally destroys the
animated

animated force, turns it into a dead one, and it therefore yields to an insurmountable obstacle in the same manner as a dead force would do. But it is otherwise when slight obstacles are overcome; for such are past over with a force, as the squares of the velocities multiplied by the weight of the body in motion. We must not therefore, concludes *Leibnitz*, estimate the force of a body in motion, by computing the force which would be sufficient to destroy that motion; since a moving body surmounts obstacles with a much greater force, than that by which its force is destroyed by insurmountable ones.

SUCH is the doctrine of *Leibnitz* upon the forces of bodies which impell each other; by which we see that he was of opinion that a body, whose swiftness was twofold, would have four times the force of one which only went forward with a single velocity. But however respectable the name of *Leibnitz* may be, there are
among

among his adversaries, names still more respectable, for *Newton* and *Clarke* are of the number. We grant, said they, that four watch springs will be coiled up by a body with a double velocity, and nine springs by a triple, and so on; but as you distinguished once, so now must we. Between the first instant that the body begins to coil the spring, and the last, in which the work is completely performed, however quick it may appear to sense, yet there passes some time. Now if we consider the effect of the coiling body at the end of the time, it will certainly produce a force as the squares of the velocities, and *Leibnitz* is in this respect right; but if, on the contrary, we could estimate the force, at the commencement of the coil, it would be simply as the velocity multiplied by the quantity of matter.

THIS dispute, which is not even yet perfectly determined, has for more than sixty years divided the learned of *Europe*, and sharpened some even into animosity; however,

however, it is only a debate merely speculative, and may be reduced to this frivolous question; namely, Whether the obstacle, a moving force surmounts, resists in succession its parts opposing, one after the other; or whether its resistance is instantaneous, all its parts opposing together? Which ever of these happens, the effect is to be measured in the same manner, only one takes in the time of succession, the other not.

NOTWITHSTANDING this dispute therefore, we may still continue to measure the quantity of force in moving bodies, by their weight multiplied by their velocity; we go on therefore to observe, that whatever be the action of a body thus moving upon another, that other exerts an equal re-action upon it. If the moving body takes three degrees of force, to drive forward a body at rest, this quiescent body employs three degrees of force, to keep the other back. If I press a stone with my finger downward, the stone presses my finger equally upward.

ward. If a horse draws a load forward, as much as he promotes the progress of the load, so much is he retarded, or in other words drawn back; and whatever motion he communicates to the load, he loses so much of his own. In a word, the re-action of any body whatsoever, is equal to the action employed in putting it into motion.

As action and re-action are thus equal, it is manifest that in the stroke one body makes upon another, the motions of both must be equally affected by the blow; and whatever additional motion the one receives, the other must lose so much that gave it; whatever the one imparts, so much must the other be a gainer.

FROM these two principles united, namely, that the force of bodies is made up of their swiftness and weight multiplied by each other, and that action and reaction are equal, depends the laws
of

of the communication of motion ; laws which ancient philosophy had never supposed to exist, and in which more modern philosophers were for a long time mistaken.

How one body becomes possessed of a power of granting its motion to another, how matter, which is itself inert, should be capable, when moved, of communicating its activity ; these are questions which we may ask, but can never resolve ; perhaps our wisest answer will be, with *Malbranche*, to say, that *God* has willed it to be so. But though we are ignorant of the cause of its motion, yet, by certain laws, we can readily tell the precise quantity of motion (or let us call it force) which one body communicates to another, provided we know the weights of the two bodies, and their swiftness before they impinged.

If we could suppose all bodies perfectly hard, it is manifest, that if thus circumstanced,

franced, any two of them should strike against each other in an even direction, they would never separate after the stroke, but either remain together immoveable, or go forward together with one common and equal swiftness. For what is it that could separate them? They cannot recoil from each other, for this would imply that their parts gave way, which they cannot do, as the bodies are supposed to be perfectly hard, and therefore unyielding. They cannot be separated by the air, or any other external resistance, for these, in the present case, are supposed to be removed. If two perfectly hard bodies therefore strike against each other, if they move after the stroke, they both move together the same way.

ALL bodies perfectly hard may be called non-elastic bodies; these, after the stroke, never separate from each other, but either remain together immoveable, or go on with one common velocity.

The quantity of force they communicate or receive from each other, may be determined in the manner following. *If two non-elastic bodies meet in opposite directions, the excess of force in one of them, before they strike, will be all that is left in both after, and this being distributed between them, in proportion to their weights, will tell us the force with which each moves after the stroke.* For all the rest was destroyed by their contrary and equal actions upon each other.

If one body in motion pursues and strikes another, which is either at rest or in motion, both bodies, after the stroke, will have all the force they had before, but then distributed between each, in proportion to their weights. For in this case there is no contrary agent to destroy their conspiring forces; and as they both move together with equal swiftness, from their want of elasticity, the force of either must be computed by its respective weight, their velocity being the same.

THESE

THESE are the great laws found out by Sir *Christopher Wren*, for measuring the quantity of force communicated or destroyed by the mutual pertussion of non-elastic bodies; and we can, with great ease, apply those rules to any particular cases that may be stated; as when one body is only in motion at the time of the stroke, or when both move in the same direction; when they move in opposite directions, and this with equal or unequal force, or unequal weight. Any of these cases, I say, may be very easily solved, by applying to the rules above mentioned. I shall only therefore take any one of them as an example at a venture, for as it is a business rather of calculation than curiosity, such learners as are delighted with studies of this nature, will very easily solve the rest themselves. Let us suppose then two bodies of unequal weight, both moving, and the one overtaking the other. Let us suppose the weight of the preceding body to be one pound, and let it have three degrees of

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velocity,

velocity, so that its force will be three. Again, let us suppose the pursuing body to weigh two pound, and to have a velocity of six degrees, so that its force will be twelve. Now I desire to know with what degree of force these two bodies will proceed after one has struck the other? First then, according to my rule, I find the force in both bodies before the stroke, which is three, and twelve, and that makes fifteen. Now this I distribute between the two bodies, after the stroke, giving to each in proportion to its weight. The first weighs one, the last two; therefore the force in the first body, after the stroke, will be five, and the force in the last body, after the stroke, will be ten. Now if I desire to know what force was communicated by the striking body to the smaller; the force of the smaller body before the stroke was three, and after the stroke five; therefore the motion it received by communication was two.

AND

AND what is thus found exact in theory, will be found nearly true in experiment. I say only nearly true, for in the whole circle of nature there is not to be found a body perfectly non-elastic, and the philosopher in this case, is obliged to be content with employing in his experiments, such bodies as are most void of elasticity. If bodies were perfectly hard, they would be perfectly non-elastic, as their parts, upon pressure, would never give way; but as in nature those substances we meet with that have hardness, have great elasticity also; the natural philosopher, in his experiments upon non-elastic bodies, instead of using unyielding hard bodies, as they are not to be met with, is obliged to have recourse to soft bodies that are non-elastic from a different principle; they yield to pressure, but do not recover themselves with a springy or elastic force.

THE substances, usually employed in experiments upon non-elasticity, are balls

made of moist clay, and suspended by fine strings, as we usually see pendulums. These are let fall from certain heights, and the time they take to pass through these heights is considered as their velocity. With these the experiments are found to answer nearly to the theory; their still having a small degree of elastic force, and the resistance given by the air, causes the deviation.

By these we can experimentally be convinced, that bodies, when they hold a certain proportion, are moved, and remove each other in equal proportion. But it is otherwise if the difference of the two bodies be very great; if I strike a clay ball against the wall of an house, the wall remains unmoved as before, or the motion is so infinitely small, that sense is not capable of discerning it. And this may serve to refute the noted opinion of the Epicurean sects, that no motion was ever lost in the world, but that what was once begun, though it ceased

ceased in the first body that received it, yet it was only by its being transmitted to another, but not actually destroyed. It is true, they may reply, that though motion be infinitely diminished, yet this is not equivalent to its being actually destroyed. Much might be said upon this question, but we will pass it over, as a discussion of it would be a matter of use to none, and a matter of curiosity only to metaphysicians.

CHAP. XIV.

Of Elasticity, and Elastic Bodies.

AS there are no bodies in nature that are perfectly non-elastic, so none are endued with perfect elasticity. By elasticity, I mean that spring or power with which we find many bodies, when pressed, restore themselves, as soon as that pressure which bent their parts together is taken away. Thus a watch spring, which, when coiled up, unfurls itself as soon as at liberty, may be called elastic; marble, which, when struck against the pavement, rebounds to some height, may be called elastic. No body on earth, even water, as we shall see in its proper place, is entirely without this power, and yet no body in nature has this power in perfection. To be perfectly elastic, the body must restore itself with a force exactly equal to the pressure made upon it. The marble, if dropt from an height of three feet, to be perfectly elastic,

elastic, must rise to the height of three feet. It falls to the pavement, is pressed inwards by the fall; if it recovered from that pressure with equal force, it would rise as high as it fell. But no body is found to do this completely; an ivory ball is the most elastic body that we know of, and such are used in all the experiments upon this subject. But before we begin to measure the efforts of this elastic power, it will not be amiss to enquire from whence the power itself proceeds.

SUPPOSE I hold, by one end, a bit of catgut moistened, between my fingers, and lengthen it by pulling at the other; this, when let free, will again shorten itself as before it was drawn. Now it is required to explain what power it is, which thus shortens the string which I had lengthened? A common observer would say, that it shortens itself, that the fibres of the string which were lengthened by force, when that force is removed, again
resume

resume their natural state. But what is the natural state of its fibres? Mere matter is intirely inert and passive, and the fibres in one situation, are as naturally placed as in any other. There must therefore be some other power, that thus impells those fibres again to contract; and what that power is, is what philosophers enquire,

To solve this question, a *Cartesian* will say, that by lengthening the string we lessen its pores, and thus squeeze a certain subtile fluid, supposed to be in all bodies, into a narrower compass, which by its endeavouring to fly out, will produce an endeavour in the body to resume its form. This solution, is a more incomprehensible difficulty, than that which it is brought to explain.

OTHER philosophers, at the head of whom is *Malebranche*, suppose that all bodies are filled with little vortexes, which, like watch springs coiled, give way

way to pressure, but restore themselves upon its removal. This is only supposing one kind of elasticity that we do not see, to prove another that we do see.

THE followers of *Newton* say, that this power is nothing else but that of attraction. When the string is lengthened, say they, its parts are not however drawn out of the sphere of each other's attraction, by which they were held together; and as soon as the power that lengthens the string is removed, and the attracting parts are permitted to resume their functions, they again attract and contract the parts to their former situations, and the string shortens as in the beginning. A single question will serve to invalidate this solution. Why then are not heavy bodies, which have most parts, and should have consequently most attraction, the most endowed with elasticity?

WHAT the cause is therefore, that a body, when thus lengthened, recovers
its

its former shortness when the lengthening force is taken away, as yet appears inscrutable. All that we know is, the actual existence of the experiment; and perhaps this is as much as is worth our knowing. Now methodically to shew that a string may be lengthened, and yet recover its former shortness, the following experiment will serve. If the string of a fiddle or an harpsichord, (fig. 26.) be stretched between two fixed points, G, H, and let it be struck upon by a solid body, sufficient to bend it from the point from I to K; it is evident that this stroke will lengthen the string, for the line G K H, is obviously longer than the straight string G H. The string therefore is lengthened by the stroke, and were it perfectly void of elasticity, it would continue lengthened.

NATURE however has endued the string with an elastic power, a power which will induce it to shorten, and re-
store

store itself with nearly as much force, as that of the body that gave the stroke. So that therefore being lengthened to K, as I said before, it will, by its elasticity, return back to I. Now the velocity which it acquired by coming from K, being in proportion to the elastic force which acts continually, will be continually accelerated, and will drive the string in the opposite direction to L. The elastic power may in this case be resembled to the gravitating power which we formerly described in the pendulum; where we shewed, that whatever heights the vibrating body falls from on one side, so much will it rise on the other. In this manner will the elastic string continue to vibrate from one side to the other for some time, and if perfectly elastic, and not resisted externally, would continue to vibrate for ever. And what is remarkable enough, each of its little vibrations, like those of a pendulum, will be performed in times exactly equal to each other.

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THE very same thing that is here demonstrated concerning strings, will be found true of all other elastic bodies whatsoever; like these, their parts give way, recover, and put themselves into a vibratory motion. Let us, for instance, take a small bell or drinking glass, and ring them at the edge with the finger; the stroke of the finger presses the edge of the glass, and for that instant alters its form; from a circle it becomes an ellipse, in form of the dotted circle A B, (fig. 27.) but upon the pressure being removed, it instantly recovers its former figure, and the restitutive force acting upon it constantly, it will acquire such an accelerated velocity, as to drive it into the opposite ellipse C D. Thus will it continue to vibrate backward and forward, from one ellipse into the other, till the resistances it hath to encounter, from its non-elasticity, and from the external air, entirely destroy its motion.

IN the same manner will other elastic bodies change their figure, making allowances

ances for the stiffness and uncompliance of their matter or figure. The parch-ment of a drum becomes alternately concave and convex; an ivory billiard ball, let fall upon earth-stone, becomes an ellipsoide by the fall, but soon alters its figure again.

BUT perhaps it may be thus objected: How do we know, that an ivory ball, which to all appearance is composed of parts stiff and uncomplying, does thus yield to the impressiion, and then recover its former figure? An experiment will prove that it yields. Let a smooth marble hearth-stone, or such like, be smeared slightly over with oil, and then let an ivory ball be dropped upon it, and it will leave a pretty broad spot upon the stone. Now it will be owned, that this ball upon the fall would touch the marble only in a single point if it were inflexible, but by yielding, it levels a part of its surface to the pressure it receives from the surface of marble, and marks it with the impressiion as before.

FROM

FROM hence we may gather, that all elastic bodies, how different soever their figure, yet exert this force in the same manner; that an elastic string and an elastic ball resist pressure just alike, and take the same methods to recover their former shapes. And from hence we may infer, that an elastic string or body, when lengthened or dilated, recovers its former tension with an accelerated velocity: thus the string in returning from K, was uniformly accelerated till it came to I: thus in the figure representing a bow string, the arrow would not quit the bow till the string arrived at the middle point, where it acquired its greatest velocity.

HAVING thus shewn the manner in which an elastic body resists pressure, it is now time to measure the quantity of motion received and communicated by elastic bodies that strike each other; and as it is impossible to throw that degree of perspicuity into this subject which I could wish in the compass to which I have

confined myself, I shall adopt *Helsbam's* manner, which, though some may think difficult, is allowed to be the best and plainest yet published. In establishing the theory of which we must suppose the bodies perfectly elastic, and all external resistance from the air taken away. In the shock of elastic bodies, nature follows the very same laws as in that of non-elastic bodies, but with this difference, that elastic bodies fly off after the shock with as much force as that with which they came together, whereas if they were non-elastic, they would destroy each other's motion entirely. The rule for determining the quantity of force in elastic bodies, after the stroke, is this.

Let the two striking bodies be first considered as non-elastic, and let the force of each body after the stroke be found, as also the force communicated from the one to the other. Then as they are elastic, let this force be subducted from that of the striking body after the stroke, and added to

that of the body which received the stroke, and the residue will be the force of the striking body, and the sum the force of the other body after separation.

THIS is demonstrable; for with whatever force the bodies struck each other, by virtue of their weights and swiftness, they will recede as much by virtue of their elasticity, and throw one another contrary ways, each with a quantity of force equal to that which the striking body communicates to the other; for which reason, if that force be subducted from the force remaining in the striking body after the stroke, as being contrary thereto, and added to the force of the other body after the stroke, as conspiring therewith, the residue and sum will give the forces of the bodies after separation.

THESE general expressions will be better understood, by making particular applications. If two equal bodies meet

one

one another with equal forces, they will be reflected back with the same forces and the same velocities wherewith they approached. For if non-elastic, they would upon the stroke destroy each other's force; but by the rule each of them must, on account of elasticity, receive as much as they gave; and the forces which are thus received by the bodies being equal, must carry the bodies backward with the same equal force wherewith they approached.

IF a body, perfectly elastic, strikes another of equal magnitude at rest, the striking body will communicate all its force to the other, and remain at rest itself. For if they were non-elastic, the striking body would upon the stroke communicate half its force, (as may be easily calculated;) and by the rule now laid down, a quantity of force, equal to that communicated, must be subducted from the striking body, and added to the motion of the body which receives the stroke, by which means

the striking body will have no force left; but the other will have a quantity of force equal to what the striking body had before the shock.

If two elastic balls be unequal; for instance, if one be double the other, and if the greater have nine degrees of velocity and the lesser be at rest, they will both move forward after the stroke; the striking body with one third of the force which it had before the stroke, and the other with two thirds; and the velocity of the striking body will be three, and of the other twelve. For since the striking body is to the quiescent as two to one, if non-elastic, it would communicate one third of its force; and being elastic, a quantity of force equal to what is communicated, must be taken from the force remaining in the striking body, and added to the force of the other; consequently the striking body will retain one third only of its force, the other two thirds being communicated to

to the body which receives the stroke; wherefore, since the striking body weighs double, or is two, and its velocity nine, its force must be eighteen, one third of which, to wit, six, it will retain after the reflection, and the other two thirds, to wit, twelve, will be the motion of the other body; and these motions being divided by the bodies, will give three and twelve for the quotients; which quotients are as the velocities of the bodies after reflection.

ON the other hand, if a small elastic ball strikes a larger at rest, let us suppose the smaller ball to have nine degrees of velocity, and weigh one pound, the larger, which is at rest, to weigh two pound. The force of the smaller will be nine, and it would, if non-elastic, communicate two thirds of this force upon the stroke to the greater, and only one third remain in it which is the striking ball. Now on account of the elasticity,

we must subduct from this remainder, as much force as was communicated, namely, two thirds; but upon subducting two thirds from one third, there will remain one third negative, which shews that the striking ball will be reflected with one third of the force it had at the time of the stroke, so as to ascend backward with a velocity of three. But the greater ball, to which two thirds of the striking ball's motion was communicated by the stroke, will likewise, on account of the elasticity, receive two thirds more, so as to be carried forward with a force equal to what the striking ball had at the time of the stroke, and one third more; that is to say, with a motion which is as twelve, which being divided by two, the weight of the ball, gives six for the velocity with which the ball will recoil,

IF two equal elastic bodies move in the same direction, and in such a manner as that one may overtake and strike the other, upon the stroke, they will exchange

change their quantities of force with each other. For instance, if the force of the subsequent body before the stroke be double the force of the preceding body, then will the preceding body after the stroke, have double the force of the subsequent body after the stroke; and the preceding body after the stroke, will move with the same velocity the subsequent body moved before the stroke; and the subsequent body will, after the stroke, be carried with the velocity of the preceding body before the stroke: so that upon the stroke the bodies will exchange their forces; but as the weights of the bodies are the same, we may in other words say, they will exchange their velocities. For let us suppose the sum of the forces to be three, and as the bodies are equal, the force of each after the stroke, if they were non-elastic, would be one and an half, and the force communicated would be one and an half; and so likewise will the force arising from elasticity, which being deducted from the

force which remains in the striking body after the stroke, and added to that of the preceding body, leaves the force of the former as one, and the latter as two, so that after the stroke the forces will be exchanged,

If the bodies be unequal, and move the same way, their forces and velocities after the stroke, may in like manner be discovered by the help of the rule. For instance, if the subsequent be two pound, and have twelve degrees of force, and the preceding be one pound, and have three degrees of force; the force of the subsequent body after the stroke will be eight, and that of the preceding body seven; and the velocity of the former will be as four, and that of the latter as seven. For the sum of the two forces before the stroke being fifteen, and the bodies being as one and two, the force of the lesser body after the stroke, if non-elastic, would be five, and that of the greater ten. But the force of the lesser body,

body, before the stroke, was three, consequently the communicated motion is two. Now adding so much, on account of elasticity, to the motion of the lesser body, and subducting as much from that of the greater body, we shall have eight for the motion of the greater, which being divided by two, the quantity of matter in the greater, gives four for its velocity; and we shall have seven for the motion of the lesser body, which, because the weight in the lesser is one, will likewise express the velocity.

If two bodies meet each other with unequal forces, if their weights be equal, they will both be reflected, and each of them will recede with the force and velocity wherewith the other approached; that is, they will exchange their forces and velocities. For let us suppose the motions of the two bodies to be as six and three; if they were non-elastic, the body which has the smallest quantity of force, would upon the stroke be turned back,

back, and the two bodies would be carried with the difference of their forces divided equally between them; that is, the force of each would be as one and an half, and the force communicated would be as four and an half. But a quantity of force, equal to what is communicated, must be subducted from the force remaining in the striking or greater body, and added to the force of the other; that is, four and an half must be subducted from one and an half, and likewise added thereto, whereby there will be three negative for the force of the striking or greater body; which shews that it will be carried back with a force as three; and there will be six positive for the force of the other body, which shews that it will be carried with a force which is as six, in the direction of the striking body before the stroke, that is, it will be reflected; so that each of them will be carried back with the motion wherewith the other approached.

If

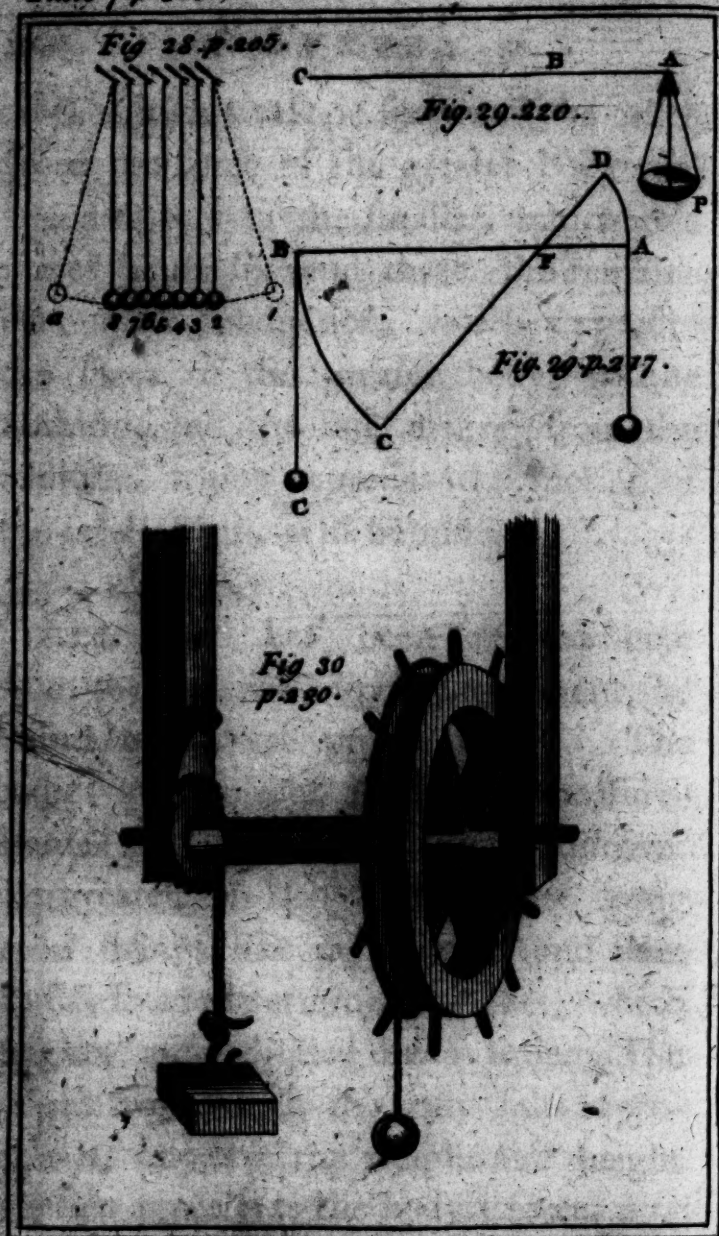
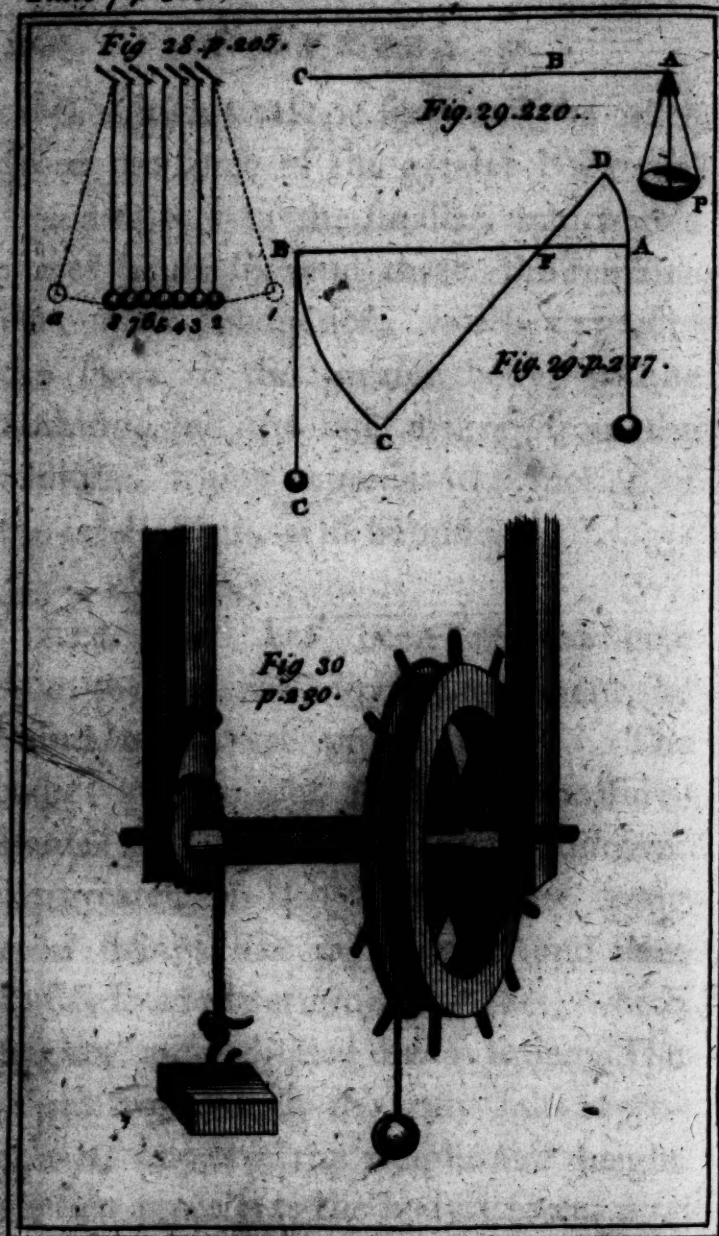
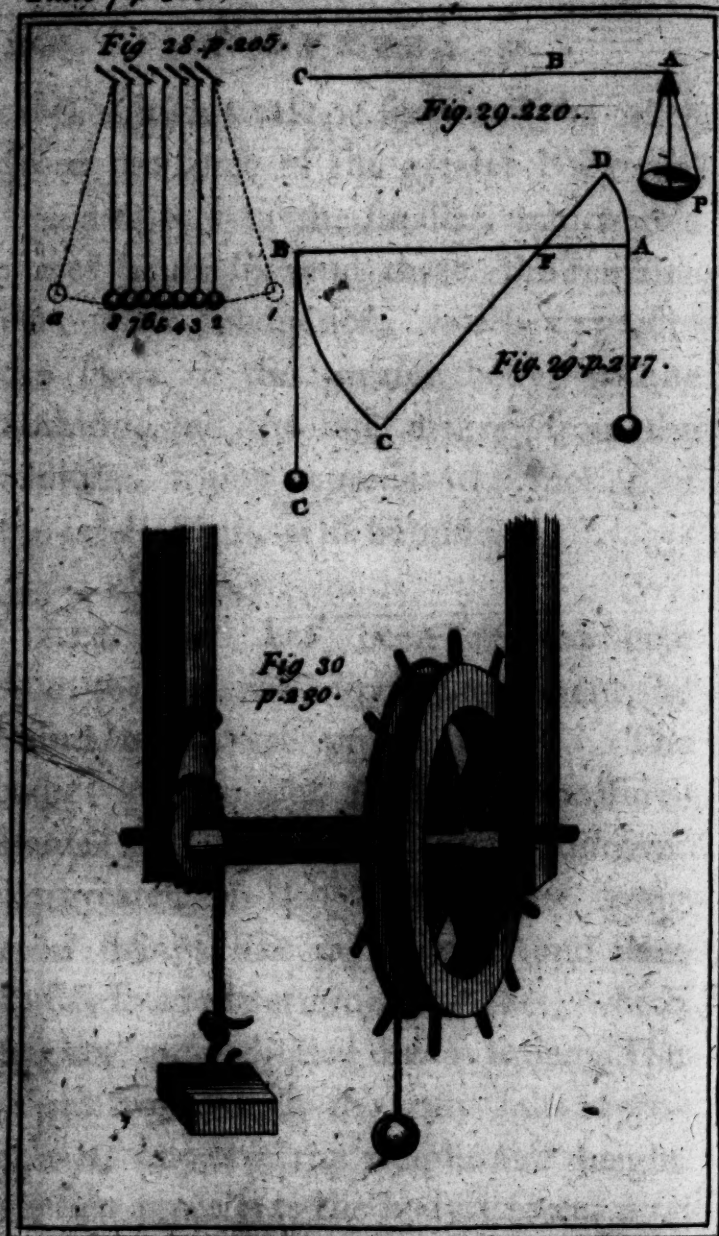
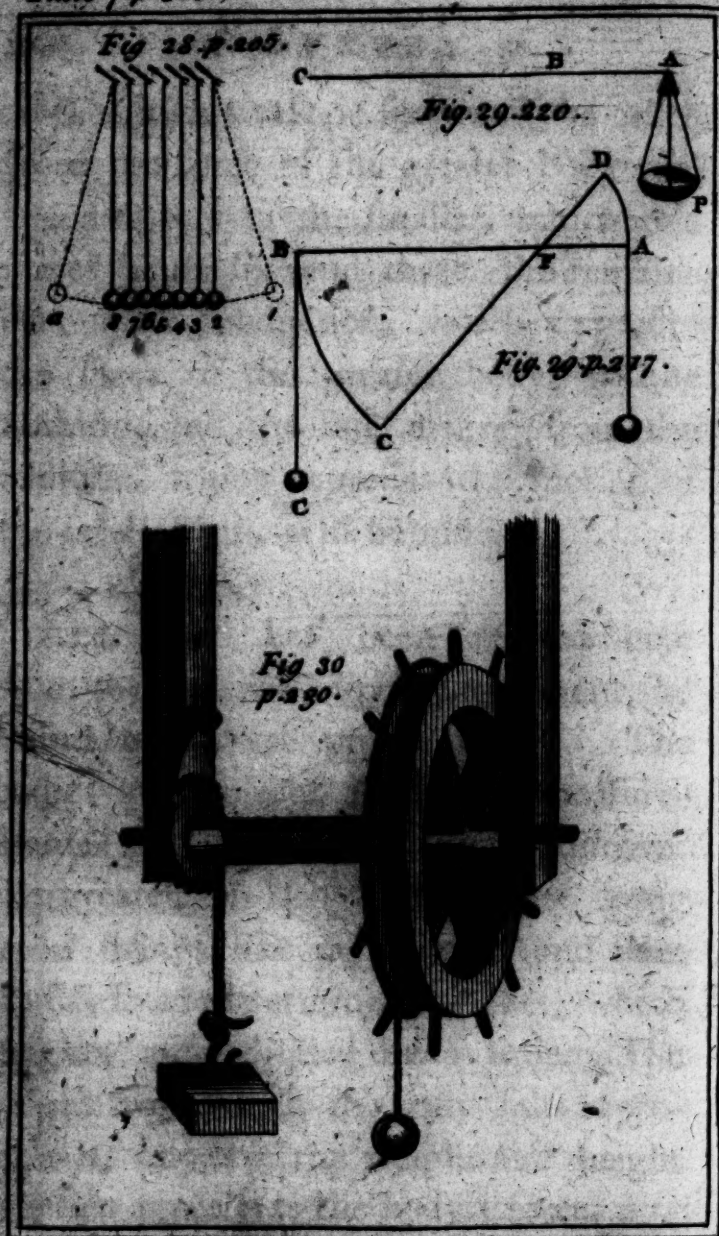
If the balls be unequal and meet each other with unequal forces, their forces after the stroke may in like manner be determined by the rule. For instance, if two bodies, one weighing two pound, and with six degrees of velocity, the other weighing one pound with three degrees of velocity, and these strike each other in opposite directions; in this case, the greater ball will upon the stroke lose all its force, and the smaller will be reflected with the difference of their forces. For supposing them non-elastic, the force in the larger, which is two, multiplied by six, makes twelve; the force of the lesser, which is one, multiplied by three, makes three. The difference therefore of their motions is nine, and this being divided between the bodies, in proportion to their quantities of matter, gives six for the motion of the larger, and three for that of the smaller; now by reason of their elasticity, a force equal to what is communicated by the striking or larger body to the other, which

which in this case is six, must be taken from the force of the greater body and added to that of the smaller, which two forces being six and three, the remainder, after subduction, which expresses the force of the greater body, will be nothing, and the sum arising from the addition, which expresses the motion of the smaller ball, will be nine.

ALL that has' been asserted here from theory, will, upon experiment, be found to answer pretty nearly. The bodies made use of in such admeasurements are ivory balls, which discover the greatest elasticity. They are hung upon strings like pendulums, and then let fall from determined heights, which heights are adjusted by a scale. The height from which the body falls represents its velocity, the weight and height together represents the body's force.

WHAT has been said of two elastic bodies, will be found also to obtain in
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the shock of several. For suppose several hung up contiguous to each other, (fig. 28.) and the ball 1, be let fall by a string upon ball 2, the stroke will be immediately and almost instantaneously communicated through the whole range of balls, and ball 8 will fly off to *a*, which is an height equal to that from whence ball 1 fell. If instead of one ball being let fall, we should drop two in the same manner, then ball 7 and 8 would both fly off to the same heights from whence ball 1 and 2 were let fall. In the same manner, if we let three fall, three would fly off on the opposite side, and thus of any number whatsoever. The reason of all this is sufficiently apparent; for if we only recollect that each ball, when struck, alters its figure into an ellipsoide, and by this means strikes against that next to it, this other communicates the same to the next, that again to its contiguous ball, and so on through the whole range, till the last ball meeting with none other to resist it, flies off with the motion of the striking

striking ball, leaving that and the intermediate ones at rest.

THE force will be thus communicated if the balls are equal; but if the striking ball be less than the balls at rest, and if these increase in weight one above the other in proper order, the force in the last ball that flies off, will be considerably greater than that of the ball which first made the stroke; and this force may be increased to any degree whatsoever. For let us suppose but two balls only, the smaller ball must upon the stroke, if it were non-elastic, communicate more than half its force to the greater ball, and there must likewise be, on account of elasticity, as much more subducted from the smaller ball, and added to the larger; wherefore, since two equal quantities of force, each of which exceeds half the smaller ball's force, are to be subducted from the smaller ball, and given to the larger, it is plain that the smaller must lose all its motion and something more, that
is,

is, it must recoil back, and the greater ball must go forward with more force than was in the smaller at the time of the stroke, that is, its force will be augmented. Now therefore, if a force be communicated from a smaller elastic body to a larger, by means of several intermediate bodies each larger than the other, the motion will be augmented in each of them, and the motion of the last will greatly exceed that of the first; and this force will be conveyed with least diminution, if the weights of the bodies rise above each other so that the last be as much greater than the former, as that is exceeded by the foregoing. As an instance how prodigiously force may be augmented by being successively communicated through a range of bodies, increasing in this progression: If twenty elastic bodies be placed one after another, each succeeding body being twenty times greater than that next it, and if a force be impressed upon the smallest body, the last body will fly off with a

force two hundred thousand times greater than that with which the smallest body first struck the range. If we should suppose a cannon ball, shot from its culverin, to be elastic, and striking with all its force a range of balls, increasing in the proportion above mentioned; what an amazing effect would it not have. But such a swiftness would quickly destroy itself; the ball, from the resistance of the air to its passage, would fly into a thousand pieces; for no stroke that we have an idea of, could equal that with which the air, however yielding it may appear to us, would act upon a body thus violently carried against it.

C H A P. XV.

Of Mechanic Powers.

THE power which man thus finds that one body has of communicating its motion to another, has taught him to make use of some bodies to remove others which he finds necessary or proper to be removed. A weight greater than what his natural strength could manage, without some such contrivance, could never be lifted from the earth; he finds himself therefore obliged to call in the force of inanimate nature, in making such alterations as his pleasures or necessities may require. By means of levers he lifts weights much greater than his strength could overcome; with the axle and wheel he can lift them to greater heights; with the pulley to greater still; the screw, if it could move without friction, would give him greater force than any of the rest; but a machine composed of all these united, would increase his strength to a degree

surpassing credit. Bishop *Wilkins*, in a work of his called *Mechanic Magic*, asserts that he could pull up an oak by the roots with a single horse hair; and so indeed he could, if the parts of the machine did not rub against each other, and thus retard the motion. However, even as it is, we see such weights removed and raised to considerable heights, as would, to an unexperienced savage, appear the work of enchantment. Nor were the ancients without a great knowledge in this art, of increasing human strength by machinery. The stones which we see laid upon the tops of the pyramids of *Egypt*, each of which is as big as a small house, create even the wonder of a modern machinist, and teach him to reverence the superior arts of antiquity.

WE come now therefore to explain the manner in which human strength is thus assisted, and the instruments made use of for that purpose. These are called
mechanic

mechanic powers, and are said to be six in number; namely, the *lever*, the *axle and wheel*, the *pulley*, the *screw*, the *wedge*, and the *inclined plane*. Such is the number usually reckoned; some however mention the balance among the mechanic powers, and omit the inclined plane; a *Frenchman* among the moderns adds another mechanic power, which he calls *La Machine Funiculaire*. It matters little what number of mechanic powers we make, it is sufficient if we describe them all. Were whatever instrument encreased human force in moving or raising bodies by machinery, to be reckoned among the number of mechanic powers, we might add still another, namely, such a machine as would convey a range of elastic bodies increasing in the progression, which has been explained in the former chapter; this and others still might be added, differing in principles from those we are shortly to explain. But no matter for the names, let us describe the things.

THE balance, as we said, is reckoned by some among the mechanic powers; and though it does not tend to increase human force, yet it will be the properest to be described first, as it will serve to explain the rest, which are somewhat upon similar principles. Suppose I take any thing that is next my hand, a walking cane for instance, and attempt to balance it across my finger; I shall at last find some one particular part in it which being supported, neither of the ends will preponderate. The very part of it that rests upon my finger is the center of its weight, which being supported, the whole cane is supported. It is called by mechanists the *center of gravity*. If I should remove my finger from this center of gravity, which I have thus found out, towards either of the extremities of the cane, though but of the smallest distance; that side would sink towards the earth which had the center of gravity in it. Thus no body at freedom will be supported, unless the
greatest

greatest part of its weight be supported, and whatever supports that, must support the center of gravity also.

BUT though I have thus balanced the cane with some small difficulty, yet all bodies whatsoever that are at rest, are balanced in the same manner; their centers of gravity are supported upon some base or prop, which keeps them firm, and the wider the base is on which the body is supported, the more difficultly will that body be overturned. For in order to this, I must first push the center of gravity, or in other words, the greatest half of the body's weight, from off the base or prop, before the body can become top heavy; and it is plain, that it will be harder to lift the half of the body's weight over a large base than a small one. If a cask be placed upon one of its ends, for instance, it may require great strength to overturn it, because I must push the center of gravity beyond its base, which is broad; but if the cask lies

on one side, I can roll it over with ease, because the narrow base touches the ground but almost in a point, and therefore the centre of gravity may easily be pushed beyond it. For this reason it is that a cylinder, or body shaped like a rolling stone, makes many turns as it descends down an inclined plane, for the center of its gravity falls continually beyond the narrowness of the base; while on the contrary, if the same body were made square, and consequently with a large base, it would either not descend at all, or it would slide down without being once overturned in the way.

MAN himself may be considered as a body thus balanced: if his center of gravity rests upon his feet he can stand; but if it is thrown beyond this support, he must inevitably fall. A man with a burthen at his back must lean forward, for should he attempt to retain his usual rectitude of figure, his center of gravity

gravity would be altered, and he must consequently fall backward. With a burthen on his breast, he in the same manner counter-balances the weight by altering his figure in the opposite position. Almost in every instance of his motions he is obliged to make use of these balancing arts to keep himself upright; and it is usually the study of a fine painter to know how far the human figure may be bent, without its absolutely losing the center of its gravity. *Da Vinci*, one of the first painters after the revival of the art, has laid down rules upon this subject; succeeding painters have improved upon his plan: *Domponius Gaurie*, an *Italian* sculptor, who wrote a Latin treatise upon this subject, thus admirably expresses himself: *Omne corpus, nisi extrema sese undique continent, librenturque ad centrum, collabatur ruatque, necesse est.* "Every body must necessarily fall, unless it unites together in the center of all its extremes, and these are balanced against each other." What-

ever weight, saith *Watelet*, the human figure is represented as lifting, we are by no means to estimate it by its size, and so, to make it appear more ponderous, to draw it more large; no, we are to throw the whole effect of its weight into the figure that is supposed to lift it, and distort the animal form as much from the natural position, as the weight is supposed to be heavy.

IN general the human body, and every other whatsoever, will stand most firmly where the base is broadest, and bears every part of the weight most equally; or in other words, where the center of gravity lies most exactly over the middle of the base. For this reason, a man when he wrestles, generally widens his legs in order to widen his base, and thus prevent his antagonist's strength from overturning the center of his gravity.

THUS we see man and all other bodies balanced upon their centers; the bodies which

which have the largest bases, and bear the incumbent weight most equally; are most firmly fixed; on the contrary, those which have the smallest bases, or whose bodies are supported but upon a point, are least firmly placed, and may be overturned with the least sensible alteration. Now suppose we should place a wooden beam, with its center of gravity resting upon the point of an upright needle, this would not fall; for as the center of gravity is supported, so likewise would the whole of the beam be. Again, suppose the beam, thus wavering at every touch but still balanced upon the point, to be twice as long on one side as on the other; that is, suppose it one yard long on one side of the supporting point, (fig. 29.) and two yards long on the other. To it, thus balanced as it is, let us hang equal weights at either end, a pound at one end, and a pound at the other. The balance will now entirely be destroyed; the weight at the longer end, which is two yards, will instantly pre-

preponderate, and appear to be much heavier than the other. Why? The usual solution is this. Suppose the weight at the longer end B, descends to C, it will describe a space equal to BC, while the weight at the shortest end A, will at the same time rise only to D, and describe a shorter space equal to AD. The weight B therefore, which describes the largest space, will have the greatest velocity. But the force of all bodies is composed of the velocity and weight; and as B hath as much weight as A, and a much greater velocity, it will have therefore a greater force, and consequently out-balance its antagonist.

UPON this easy principle, continue they, the whole of mechanics depends; so that if two bodies are suspended at each end of a beam, or any machine whatsoever, if the one be as much superior in its velocity, as the other exceeds it in weight, the bodies will balance each other; if the velocity be greater in

pro-

proportion, that side will sink; on the other hand, if the weight be greater in proportion, that will preponderate. As for example; If the side or arm A of the beam be one yard to the prop F, while the side or arm B is two yards; as B has thus twice the velocity of A, I must make A twice the weight to counterpoise B. If B be one pound, I must make A two pounds, to keep the balance equal. So that universally to make a lighter body out-weigh an heavy one, it is but to make up the defects of its weight by increasing its velocity. Thus one pound, if it has twice as much velocity, or in other words, be twice as distant from the prop, it will balance a body that is twice as heavy as itself. A weight of one pound, if it be twelve degrees distant from the prop, will balance a weight of twelve pounds that is but one degree distant.

A COMMON pair of scales is a beam suspended upon a point or axle, and its arms

arms are equally long, and equally heavy; so that the velocity on both sides is the same, and also the weight is the same; and consequently all bodies of equal weights put into either scale, will balance each other. But this, as I said before, will not happen, if one arm of the instrument were longer than the other; for then that at the longest end having greater velocity will preponderate.

THE steelyard is an instrument of this kind, contrived for weighing bodies by a single weight, whose velocity or distance from the prop, we increase in proportion to the weight to be known. For if a scale hangs at A, the extremity of the shorter arm, and is of such a weight as will exactly counterpoise the longer arm C; if this arm be divided into as many parts as it will contain, each equal to AB, the single weight P, which we may suppose to be one pound, will serve for weighing any thing as heavy as itself,

or as many times heavier than itself, as there are divisions in the arm BC. Thus we see that one pound, at the distance of twelve, balances against twelve pound at the distance of one.

SUCH is the manner in which mechanists have usually explained this subject; and it must be owned that in practice it answers pretty exactly. Notwithstanding this, *Newton*, sagacious in all things, was sensible that the theory shewn here, was obscure and unsupported; he therefore gave a theory much more difficult, though much more satisfactory. Mr. *Varignon* and Mr. *D'Alembert* are equally displeased with the former theory. *We have not*, says the latter, *a single work on mechanics, in which the theory is proved with the exactitude it requires.* In fact, to establish the former theory, we are obliged to suppose two bodies equally at rest to have superior velocity one above the other; though, when we are asked what velocity means, it only signifies

signifies their going through more space in the same time. Now is it not evident that at the beginning of the time, neither has gone through any space at all, and therefore their velocities must be equal. So that superior velocity cannot be brought to prove why one body first begins to preponderate against its antagonist of equal weight, yet this is what we desire to know. The theory therefore must be built upon another foundation; perhaps it may be established by the method following.

WHAT I desire to know is, why a beam, with one arm longer than the other, and which being placed upon a point or prop, is exactly balanced; why, I say, when thus balanced, if I hang equal weights at either end, the beam shall no longer continue in balance, but the longer arm shall preponderate? To explain why this is so, it must again be repeated, what was said of the center of gravity, that all bodies stood most firm when the
base

base was largest, and the center of gravity was placed most exactly over the middle of the base. The nearer the edge of the base the center of gravity fell, as was said then, the readier would the body be to fall. If the center of gravity fell just without the base, the body would effectually tumble, though only with so much velocity, as the resistance of the base, which tends to keep it upright, is exceeded by the power that causes it to descend. Thus the body may be supposed as acted upon by two contrary forces, and the velocity must be in proportion to the excess of one force above the other; but small, because the difference between the gravity and the resistance is supposed to be just begun. Now if the center of gravity fell still farther beyond the base, the resistance of the base to the body's descent would be still less; for as we said, the base gives most resistance when the center of gravity is in the middle, and therefore the farther the center of gravity is removed from

its

its middle, the less resistance will it give; and therefore the body will be more acted upon by the power which causes it to descend, and it will tumble with greater velocity. So that in general we may conclude, the farther the center of gravity falls beyond the supporting base, the swifter will be its descent.

ALL this being premised, if I now inquire why a smaller weight C, preponderates in the balance, though opposed by a great one A; I answer, because the center of gravity in the beam, falls to a greater distance on the preponderating side C, than A. For let us suppose the beam F, without its weights, but balanced upon its base, which is but a point. Now if I should hang a pound at A, this would throw the center of gravity, which was before at F, nearer to A, and far beyond the base, so that A would preponderate. In order to oppose this therefore, I must hang an equal weight of a pound at an
equal

equal distance from the base on the opposite side at E, which will throw the center of gravity as much beyond the base that way, so that the center in this case, actuated by two equal forces, will still remain suspended over the middle of its point or base F. But again, if we place this equal weight at more than an equal distance, still farther to B, it is evident that it will overcome its antagonist, and remove the center of gravity at a greater distance from its base, and that therefore the body must fall that way; and consequently, as we said above, with the greater velocity. We may therefore conclude universally, that if two equal bodies be balanced upon a point, and each equally distant from it, if one of them be removed at a still greater distance, it will endeavour to descend with greater velocity, the farther its center of gravity falls beyond the base or point on which it rests. In other words, the base or point is thus rendered more distant, and consequently

less capable of contributing to the body's support.

FROM all that has been here said, we at length perceive the weakness of the former theory, and we now see that a small weight out-balances a greater, not because it has a greater velocity, but because the prop, which in some measure supports both, sustains a greater part of the large weight that is near, than of the small weight that is farther off. That the body placed at the longer end, when put into motion, hath more velocity, is most certain; but this velocity was nothing when the bodies were in equilibrium, and therefore could never destroy that equilibrium: velocity is the consequence of motion, not the cause. If it be said, that the body had a potential, or, as *Leibnitz* expresses it, a virtual velocity, though not yet exerted; this is only saying in a dark and unintelligible manner, what we have endeavoured to throw into greater sunshine.

THIS

THIS theory may, with great ease, be applied to the solution of several more complex propositions. As for instance, if a man, standing in one scale of a large pair of scales, and balanced by weights in the opposite, should extend his arm, and press the beam upward with his hand, towards the middle, this pressure would take effect, although his feet seem to press downward as much as his hand upward; this pressure upward, I say, would raise the scale in which he stands. For (to dispatch it in a few words) by extending his arm nearer the prop, he brings the general centre of gravity more within the base. It is partly owing to this, and partly to the elasticity of the muscles employed in the pressure above, while the muscles below have less employment, and consequently less elasticity.

THIS theory will serve to explain the proportions that must be observed in a balance, where one or both the arms

are crooked. All the mechanic powers may be reduced to the balance, this theory may therefore, by some attention in the students, be applied to them; it is enough here to explain the principle; such as are fonder of calculations than I am, may make the application.

THE mechanic power most allied to the balance, and in fact, scarce differing from it, is the *Lever*. A lever is a bar of iron or wood, one part of which being supported by a prop, all other parts turn upon that prop as their center of motion. This instrument is of two kinds. First, the common sort, where the weight we desire to raise, rests at at one end of it, our strength is applied at the other end, and the prop is between both. When I stir up my fire with the poker, I make use of this lever; the poker is the lever, it rests upon one of the bars of the grate as a prop, the incumbent fire is the weight to be overcome, and the other
end

end I hold in my hand, which is the strength or power. In this, as in all the rest, we have only to increase the distance between the strength and prop, to give the man that works the instrument greater power: the reason has been already explained at large.

THE lever of the second kind, has the prop at one end, the strength is applied to the other, and the weight to be raised rests between them. Thus in raising the water plug in the streets, the workman puts his iron lever through the hole of the plug till he reaches the ground on the other side, and making that his prop, lifts the plug with his strength at the other end of the lever. In this lever also, the greater the distance of the prop from the strength, the greater is the workman's power.

THESE instruments, as we see, assist the strength; but sometimes a workman is obliged to act at a disadvantage, in

raising either a piece of timber or a ladder upon one end. We cannot, with grammatical propriety, call this a *lever*, since such a piece of timber in fact no way contributes to *raise* the weight. In this case, the man, who is the strength or power, is in the middle, the part of the beam already raised is the weight, the part yet at the ground is the prop, on which the beam turns or rests. Here the man's strength will be diminished, in proportion to the weight it sustains. The weight will be greater the farther it is from the prop, therefore the man will bear the greater weight the nearer he is to the prop.

THE second mechanic power is the axle in the wheel, in which the strength is applied to the circumference of the wheel, and the weight to be raised is fastened to one end of a rope, whose other end winds round an axle, that turns with the wheel. (Fig. 30.) This instrument is more commonly used with
an

an handle: thus, to wind up a jack I turn the handle, which coils the cord round the axle in the middle: to wind a bucket from a well, I do the same thing; to wind up my watch, the same: the handle in all these is in the place of a wheel, and the farther this handle is from the center, the axle, on which the whole weight is sustained, the more powerful will it be. Or if it be a wheel, the more its diameter exceeds the diameter of the axle, the greater will be its power. Thus, if the wheel be eight times as wide as the axle is thick, it will have eight times the power; and a man, who by his natural strength, could only lift an hundred weight, by this machine will be enabled to lift eight hundred.

ONE circumstance with regard to this machine I must not omit; workmen universally affirm, that in raising weights to considerable heights, (to an house-top, for instance) with an axle and wheel, they find the weight most heavy when

Q 4

they

they first begin to wind, and that it grows lighter and lighter as it approaches the axle. The reason of this seems to be, that the weight appended at the cord, when longest, is apt to swing; and if we resolve the whole machine into a common lever, we shall find that the weight to be raised in this case, will, by swinging, either fall at a great distance from the prop, or it will fall nearer the prop, or it will fall between the prop and the power. In the first and last case, its seeming weight will be augmented, in the middle case it will be lessened. So that when the weight swings, there are two to one that the weight will appear augmented to the labourer; and the greater the swing, the greater will this augmentation be.

THE third mechanic power is the *pulley*, which is a small wheel that turns about its axis, and which hath a drawing rope passing upon it. In every clock, the two weights descend upon two little
brass



brass pullies, that fall, and are wound up with them. In our kitchen jacks, the weights descend upon pullies in the same manner. The pulley is either fixed or moveable, that is, it is either fastened to some large immoveable piece of timber; thus, A A fastened to the beam b, (fig. 31.) or it moves with the weight to be raised, thus; if I draw the cord E, that passes over the fixed pulley C, I shall raise the weight W, and the moveable pulley D, will rise as the weight rises.

A FIXED pulley that only turns on its axis and rises not with the weight, can only serve to change the direction of the moving power, which is in all cases exceedingly convenient. For instance, if the weight W, is to be raised to A, and the man cannot readily get to it, or exert his strength when he gets there, he has then only to throw the cord B round the pulley fixed at A; and standing upon the ground, and exerting his strength at D, he can move the weight
I W, to

W, to the height A intended. But though this be convenient, yet it gives him no additional power, for it is only as the beam of a balance, whose arms are of equal length and weight. Thus, if the equal weights W and P, hang by the cord BB upon the pulley A, they will counterpoise each other, just in the same manner as if the cord was streightened into an inflexible iron bar, and the two weights left to balance each other with the pulley for a prop.

BUT in the moveable pulley it is otherwise; for if a weight W hang at the lower end of the moveable pulley D, and the cord GF go under the pulley, and is fixed at the top of the hook H on one side, and nailed to the block C on the other; it is evident that H and C between them support the whole weight W; H supports one half, and C the other half. Now suppose I take the support of one of their halves upon myself, but merely change the direction of my power, and instead of holding up the
cord

cord at C, throw it over the immoveable pulley fixed there, and exert my strength below at P; it will be evident that I support one half of the weight W, and the hook H supports the other. If therefore I draw the cord at P, the weight W will continue to rise, but wherever it rises, I continue to support but half its weight, while H supports the other. Thus, one single moveable pulley diminishes one half of the weight to be raised; if we should add another, it would diminish the half of that which remained, and so on. For instance, if a weight of eight hundred pounds is to be raised, I use one moveable pulley, and that will lessen the weight one half, to four hundred; I add another moveable pulley, and that will lessen the remaining four by one half, which is two hundred; if I still add a third, that will lessen the remaining two by one half, which is one; so that if I use three moveable pulleys in raising eight hundred weight, I shall be able to raise it with as much ease, as one hundred without them.

As

As a system of pulleys have no great weight, and lie in a small compass, they are easily carried, and can be used in many cases where more cumbrous engines cannot. They have much friction however, because the diameter of their axis bears a very considerable proportion to their own diameter, because they are apt to rub against each other, or against the sides of the block, and because the rope that goes round them is never perfectly pliant.

THE next mechanic power usually mentioned is the *wedge*. Those who have seen men cleave timber, cannot be at a loss to know that the wedge is a piece of wood or iron, thin at one end and thick at the back; that the thin or trenchant end is applied to the timber to be cleft, and the thick end struck upon by an hammer. Mechanists have long debated, and still continue the argument, concerning the force of the wedge. *Aristotle* considers the wedge as two common
levers

levers inclined to each other, and acting in opposite directions. *Guido Ubaldus* refers it to the second order of levers; others again, resolve its action into that of inclined planes; and there are some still, who will not allow that the wedge gives the striker any force whatsoever. To say the truth, there are so many natural obstructions to the illustration of a theory concerning this instrument, that it is almost an useless matter, to establish a rule which no experiment can be made to confirm. The particular cases that obstruct its general theory, are either the elasticity of the wood to be cleaved, or the elasticity of the hammer that strikes, or of the wedge itself. The manner in which the wood yields to the impression of the wedge, either in being split, or cut through by it; for if split, it only touches the wedge on each side in one place; if cut through, the wood lies close to the whole surface of the cutter's instrument. Other considerations might be mentioned, but in short, the cases are

so various, that no theory can be brought to direct every experiment; nor no one experiment to confirm the theory. The following method of estimating the wedge's force, seems liable to exceptions. As much as the length of the wedge exceeds the width of its thick end or base, so much will the driver's power be increased, in overcoming the resistance of the wood to be cleft. If, for instance, the wedge be twice as long as another whose thick end is equally broad, the driver will cleave his wood with twice greater force with the former than with the latter. To prove this, if we suppose the wedge driven to its head into a block of timber, (fig. 32.) the length of the wedge *AB* will represent the space the driving force is gone through; the breadth of the wedge *DC*, the space through which it has been driven, on each side, the resisting force of the timber. Now we see that to drive the resisting forces through the spaces *C* and *D*, a driving power is employed, which



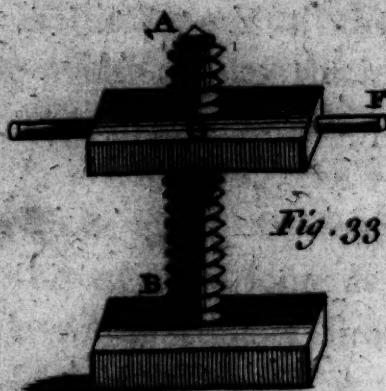


Fig. 33. p. 239

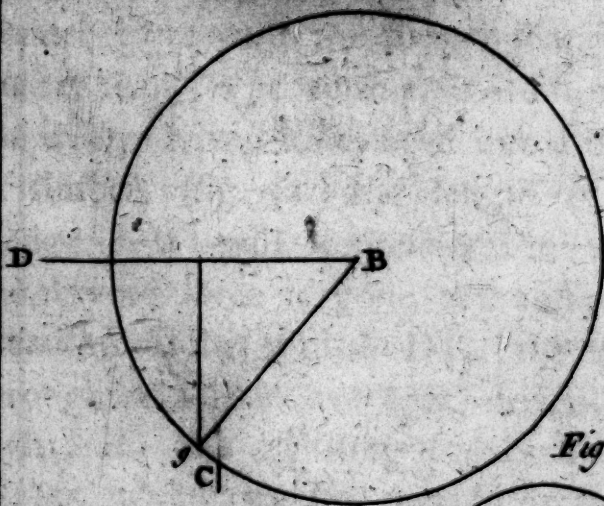


Fig. 35.
p. 270

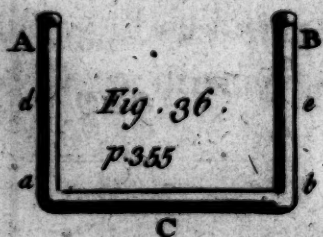
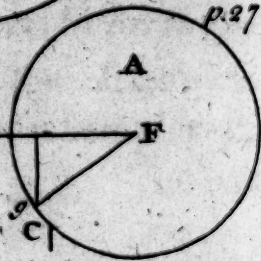


Fig. 36.
p. 355



which goes through the greater space AB. That is, in fact, if AB exceeds DC, so much will the driving force, which AB represents, exceed the resisting force. Or in other words, if the length of the wedge be greater than its thickness, the driver's power will also be greater than the resistance of the timber; if the wedge be but just as long as it is thick, the driver will have no advantage whatsoever.

THE mechanic power that comes next is the *screw*, with which most people are so well acquainted, that it needs no description. With this instrument our presses are usually driven close together with surprizing force, and held during pleasure in that position. It cannot properly be called a simple machine, because it calls in the assistance of the lever to increase its force, which is usually applied in the manner of an handle, to turn its socket upon it. (Fig. 33.) To estimate the force of this machine, let us suppose

suppose that I desire to screw down the press G upon B; every turn I make once round with both handles, I shall drive the press only one spiral nearer to B; so that if there be eleven spirals, I must make eleven turns of the handles FL, before I come to the bottom. In pressing down the screw therefore, I act with a force as much superior to the resistance of the body I desire to press, as the circumference of the circle, which my hands describe in turning the machine, exceeds the distance between two little spirals of the screw. For instance, suppose the distance between the two spirals to be half an inch, and the length of both handles 12 inches. My hands placed upon them in going round will describe a circle, which upon calculation will be found to be 76 inches nearly, and consequently this will be an hundred and fifty two times greater than half an inch, which was the distance between two of the spirals. Thus, if a body is to be pressed down with this machine,

one

one man will press it with this assistance, as much as an hundred and fifty two men without it. Or if the screw were so contrived as to raise the weight instead of pressing it, which it sometimes is, the human force would be assisted in the same proportion with the same instrument. But we here only talk as if the handles of the screw were but twelve inches across, and the spirals a whole half inch distant from each other; what if we supposed the handles five times as long, and the spirals five times as close! the increase of the human force then would be astonishing!

To these, which usually go by the name of mechanic powers, and of which alone all complicated machines whatsoever are supposed to be made up, and each of which act but with one power on the weight at a time; to these, I say, Mr. *Varignon* has added one more, which he calls *La Machine Funiculaire*. This is a composition of cords, many

of which different powers act upon one or more weights at the same time; and by which, from their conspiring with each other, a greater force is exerted than would arise from the sum of all the cords, singly applied to the weight to be removed. They who have seen the common ludicrous method of placing three spoons upon a table each supporting and supported, will have some idea of a machine of this nature.

SOME add to these powers also the inclined plane, and indeed not without reason, if diminishing the weight of a body laid upon it can entitle it to the name. The properties of the inclined plane we have considered already; we shall only here say, that the more the plane is inclined, the easier a body may be rolled or forced up its surface; or in other words, the advantage we gain by it so much exceeds the absolute weight to be raised, as the length of the plane exceeds its height. Suppose CD (fig. 34.) be

be an inclined plane, and suppose its whole length be three times as great as its perpendicular height FG ; in this case the roller E will be supported upon the plane, and kept from rolling down by a power equal to a third part of the roller's weight. A weight therefore may be rolled up this plane, with three times greater ease than it could be lifted up directly from the perpendicular G to F .

By one or more of these simple powers, all great weights are raised to considerable heights; but in them all, the more they diminish the weight, the more slow they are in their operations, and consequently the more do they retard the workman's dispatch; and universally the more simple they are, the more expeditious. Besides this, their friction or rubbing against each other, greatly diminishes their power. The friction in the balance is least, it is more in the lever, increased in the axle and wheel,

yet more in the pulley, but most of all in the screw. In general, in combined engines, upon account of this friction, they will require a third part more of power to move them, than the theory allows. For this reason therefore, it will for ever be impossible to fulfil the boast of *Wilkins*, who vaunted that he could pull up an oak by the roots with a single horse-hair; for the force requisite to work the machine in pulling it up, would nearly amount to a third part of the force which the machine exerts. The large capstan and pulley, used in launching a man of war, would in theory do it most effectually. A simple lever, drawn a proper length by the imagination, would do it as well; it would even fulfil the great boast of *Archimedes*, it would remove the earth itself. The learned often amuse themselves with fancies like these; and it was for this that *Cicero*, who was perhaps the wisest man, called *Archimedes* a trifler.

C H A P. XVI.

*Of Man, considered as an artificial
Machine.*

MAN has been considered by anatomists, as a system of all the artificial machines united in the human fabric; they have found the lever, the pulley, the axle in the wheel, the wedge, and even the screw, or at least something resembling each of them, in his person: thus, his arms have been likened to levers, his head turning upon its axle, the digastric muscle that assists his swallowing, to a rope running over its pulley, the glands as lifting up their fluids in the manner of an artificial water screw, and his teeth have been compared to wedges. But some have not stopt here, they have gone on not only to please themselves with the resemblance, but to estimate the force of man through all his vital and involuntary motions, such as the running of the blood through his veins, the

drawing his breath, and such like, by the inflexible laws of mechanisim. They have even applied geometrical rules to measure objects constantly in change, and built theories upon proportions they were unable to discover. Thus when *Borelli* once got the hint of comparing the muscles or fleshy parts to cords, he then readily built this theory, and calculated the human force, by considering the thickness of the cords, and the length of the lever. Thus, when another found the similitude between the blood running through its channels, and water spouting through pipes, he pursued the speculation, till he at last was taught to believe that vomits would cure a spitting of blood, and bathing in warm water would be a remedy for the dropfy; happy however, had his theory never been put into practice.

IT is as impossible to determine the muscular force of any man, by the bare inspection or admeasurement of his muscles,

muscles, as it is to measure the swiftness of the circulation of his fluids; by the spouting of his blood from a vein. Neither can be done, though *Cheyne* has pretended to demonstrate, that if we compare the muscular strength of two animals, that animal whose fluids circulate twice as swift, will be six times as strong. *Friend* and *Wainright* adopted his demonstration, for he called it a demonstration, and indeed it was drawn up with a sufficient degree of mathematical parade. *Martin* however, in a treatise entitled *de similibus animalibus*, has demonstrated that *Cheyne's* demonstration was false; but it was in order to establish another demonstration of his own. He asserted, that the force in similar animals, was as the cube roots of the fourth powers of the limb put into motion. The learner will not perhaps understand the precise meaning of these words, but it is no matter, for his demonstration is as false as the former.

FROM the mere dimensions of the muscles in two similar animals, it is im-

possible to determine their force. The strength of the muscle is generally more in proportion to the exercise it has been employed in, than to its size; the legs of a chairman are stronger, the arms of a smith; in short, to use the words of a bully, in a *Spanish* comedy, who mistook his man and was beaten, we can never know the strength of the muscles, till we experience their effects.

BUT though we cannot determine with any precision, of two men which are strongest, yet in the same man, we can compare the force of his muscles with rather more precision: this at least can be said with great certainty, that those muscles which are inserted into the bone, nearest to the place where it moves upon another, overcome the greatest resistance, and consequently act with the greatest force. But to a learner this wants explanation.

ALL

ALL our flesh is composed of muscles, which (if I may use a vulgar similitude) are like red ribbands, and almost all have one of their ends fixed into one bone, and another of their ends into some other bone. Thus, if we feel the great ham-string, which is made up of many muscles, we shall find that at one end it is fixed into the bones of the leg, just under the knee, and at the other end it runs upwards, partly to be fixed in the great bone of the thigh. The muscles being thus stretched from one bone to another, have a wonderful power of contracting and shortening themselves at pleasure; and when we chuse to put them into action, they swell in the middle, somewhat into the shape of a ninepin. As these muscles thus contract, they must necessarily draw the two bones, into which they are inserted, their own way; the ham-string, when it contracts, for instance, draws the leg backward toward the thigh; when we want to make the limb straight, there are muscles
inserted

inserted under the fore part of the knee, that contracting, answer this purpose; while, in the mean time, the hamstring suffers itself to be relaxed, in order to let the opposing muscles take effect. This being understood, it will follow, that if we consider any one of the bones, the arm bone for instance, as a beam, and the muscles that raise it and put it into motion, as the power that agitates and works the instrument, the whole will give us the idea of the third kind of lever, where the prop is at one end, the weight to be sustained at the other, and the strength is applied between them both. Thus for instance, if I stretch out my arm, the prop is in the joint of my shoulder, the weight is my hand, and the raising power is the muscles, which are fixed into the arm bone near the shoulder, and go from thence to be inserted into the bones of the trunk of my body. Now the nearer the shoulder these muscles are inserted into the arm bone, it is evident that the longer will

be the lever, against which they are to act, and consequently the greater will appear the weight which they are to sustain. To make this quite plain, suppose a ladder were laid flat on the ground; and suppose that I standing at one end, take the nearest round of the ladder in both my hands, and thus pulling back attempt to raise the farthest end, keeping the nearest end still steady to the ground. Would not this require immense strength to effect? Pretty similar is the force that the muscles of the arm exert in raising the whole length of the arm, and the weight of the hand beside. They are inserted into the bone close to the shoulder, and support the whole length of the arm in the desired direction. But what is more, they do not only act upon the lever at so disadvantageous a distance, but also they act upon it in a direction the most oblique, and consequently at a greater disadvantage still. Suppose I attempt to raise the distant end of the ladder by pulling the round nearest me; this, as I said,

said, will be very disadvantageous: but suppose yet farther, that I should first lie upon my back, and then by drawing the next round to me of the ladder, I should attempt to raise the distant end; the force that would be capable of effecting this, would be incredible. Yet in this very manner it is that the muscles of the shoulder act, in raising the arm. They are not only inserted at the greatest distance from the weight, but they exert their power the most obliquely. The force they exert in keeping the hand and arm extended is great; the force they exert in keeping it extended, while the hand holds a weight of about twenty pounds, is astonishing. Some say that these muscles, upon equal terms, would lift a weight ten thousand times greater. What has been here said of the muscles of the arm, is true, in a greater or less degree, of all the muscles of the body; so that this natural machine, thus fashioned by the Great Workman, is infinitely more powerful than any artificial

artificial machine that man could form, though it took up four times the space.

THE muscles, as we said, are supported by bones; these make altogether a single pillar or column, which though not perfectly straight, but with about five different curvatures or bendings; yet when perfectly balanced upon itself, will actually support weights that would surprise the inexperienced. *La Hire*, and *Desaguliers* give us several accounts of the amazing weight some people have sustained, when they were able to fix the pillar of their bones directly beneath it. The latter tells of a *German* who shewed several feats of this kind at *London*, and who performed before the King and a part of the royal family. This man, being placed in a proper situation, with a belt which rested upon his head and shoulders, and which was fixed below to a cannon of four thousand weight, had the props which supported the

the cannon taken away, and by fixing the pillar of his bones immoveably against the weight, supported it with seeming unconcern. There are few that have not seen those men, who, catching a horse by the tail, and placing themselves in direct opposition to the animal's motion, have thus stopt the horse, though whipped by his rider to proceed. In all such cases, the pillar of the bones is placed in direct opposition to the weight; they support each other, and are prevented from rubbing or cracking by elastic gristles fixed between each bone; these give way a little upon great pressure, and restore themselves almost instantly, when that is removed. Besides these, there is a viscous or slimy liquor that is squeezed in, as if from a sponge, between every joint, and keeps these gristles smooth, moist, and pliant. By means of this fluid, all the joints move easily, and obey the impulse of the muscles with greater dispatch. This fluid, and the gristles (or cartilages, as anatomo-

anatomists call them) contribute not a little to the strength of the animal; they resist the burthen with an elastic force, and conform themselves to the inequality of the pressure. In old age both are diminished, the gristles become hard, and this liquor (which anatomists call the synovia) is squeezed out in less quantities. The man therefore, in old age, becomes more stiff and more weak, chiefly upon this account, though partly because his muscles become then also more rigid, hard, and less fleshy, as it is usually called; as those who have eaten the flesh of old animals know. While we are at rest, this fluid, or synovia above mentioned, oozes out between the joints, to fit them for the hour of action; when in exercise, the ends of the bones press against their gristles, and these are separated in some measure by the synovia or fluid; but there is still another liquor of an oily nature, which is pressed at the same time from a small fleshy sponge, placed in every joint, and
this

this mixing with the synovia, makes all supple and fit for business. I said, that the synovia or viscid liquor oozes out between the joints in the hour of rest; it is therefore in greatest quantity between them, in the morning, after we have taken our rest the preceding night. So great is the quantity usually separated during sleep, between the joints of the back bone, that some men are an inch taller in the morning than at night, and all men are somewhat taller, as may be quickly found by any who chuse to make the experiment upon themselves.

FROM what has been said it appears, that in carrying large burdens, the whole art consists in keeping the column of the body as directly under the weight as possible, and the body as upright under the weight as we can. For if the center of gravity in the burthen, falls without this column, it will go near to fall; in fact, if the supporter were an inanimate machine, it would fall inevitably;

tably ; but human power, in some measure, catches the center while yet beginning to descend, and restores the balance which it had lost the moment before. A man balancing under a weight, resembles one of those people whom we usually see walking upon a wire ; they totter from side to side, for a moment lose the center of gravity, but by throwing forward a limb or distorting their bodies they recover it again, to the great amusement of every spectator. It is thus, that he who carries a weight is obliged to act ; on whatever part of his body the weight is placed, he balances it by throwing as much of his column beneath the load as he can. Could the weight be laid and evenly balanced upon him, standing in his natural posture, he could, as we observed before, support an incredible burthen ; and though he could not move under what he could thus support, yet he could carry a much greater load, than if the burthen were laid in any other manner. The weight a man could support, when thus

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evenly laid upon his shoulders, would break the back of the strongest horse in the world. The reason is obvious. In a man, the whole column of bones supports the weight directly; in an horse, the weight is laid upon the column cross ways. The porters of *Constantinople* are known to carry each a weight of nine hundred pounds; they lean upon a staff while loaded, and are unloaded in the same manner. The porters of *Marseilles* in *France* are found to carry yet more; their manner is this: four of them carry the burthen between them, each having a sort of hood that covers the temples and head down to the shoulders; to this is fastened the cords that support the frame or bier, on which the weight is laid. By this contrivance the whole column of the bones acts directly against the load, and an immense weight is thus sustained.

WE now therefore at length see the reason why two men carrying a load between

between them, can sustain a greater weight than what either could separately carry, if it were divided into two equal parts. The reason is, that two men can bear the load each more upright, and with the column of their bones more opposed against it.

As man bears a weight the better, the more upright he stands against it, it must follow necessarily, that the more bendings he makes in supporting weights, the less will be his power. There are three principal bendings in the human column; the first at the hams, the second at the hips, and the third along the back bone, which resembles the osier in pliancy, though it be stronger than the oak. A man of ordinary stature and strength, upon an average, has been computed to weigh an hundred and sixty pounds; he can support, as we said before, an immense weight if his column acts directly against it; if he bends a little at the hams, such a man

may raise from the ground about an hundred and seventy pounds, provided the weights are placed to the greatest advantage. If he bends at the hips and back, he will lift thirty pounds less. If a weight be placed upon his head, and he be put between the rounds of a ladder placed horizontally and breast high, he can lift thirty pounds by the strength of the muscles of his shoulders and neck alone.

FROM this we see, that human strength is not the fourth part as great when the body is bent, as when it is upright. From this also we see, that if a man draws a load after him, as in that case all his muscles act in an oblique direction, he can exert but very little force, when compared to other animals. *Desagulier* pretends to say, that an horse can draw as much, upon an average, as five *English* workmen. The *French* writers say, *Dr. Barthes* in particular, that an horse can draw as much as six *Frenchmen*, or
seven

seven *Dutchmen*; but if the load were to be placed upon the shoulders, two men will be found to be as strong as an horse. A *London* porter shall carry three hundred weight at the rate of three miles an hour; two chairmen carry an hundred and fifty pounds each, and walk at the rate of four miles an hour. Whereas a travelling horse seldom carries above two hundred weight, and a day's journey with such a load, would be apt to disqualify him from travelling the day following,

MAN'S greatest force therefore, is directly upward; if he draws a load, he must act at a disadvantage. A man however, when obliged to draw a load, a rolling stone for instance, hath two methods of doing this. He may either turn his back to the stone, and pushing the frame with his breast, thus go onward, while the stone rolls after; or he may turn his face to the stone, and go backward, drawing the stone with

S 3

him,

him. This last method may be the most inconvenient, but it gives the workman much the greatest share of power, and that for two reasons. In the first place, by inclining farther back, he can give a greater column of his body to the draft; and in the next place, a greater number of his muscles come into action; particularly the two great deltoid muscles of the arms, the force of which is very great. It is for this reason that men who row a boat, more usually draw the oar to them, than push it from them.

C H A P. XVII.

Of Wheel Carriages.

BY what we have seen of man considered as a machine, it is easy to observe that his frame is not adapted to drawing carriages ; while on the contrary, in that of an animal upon all fours, the column of whose bodies, and the situation of whose muscles, act almost directly upon bodies placed behind them, they are perfectly fitted by nature for this kind of service. Horses are usually employed in the draft in *England*; mules, oxen, sheep, and other animals are sometimes used in other parts of the world. It might incur ridicule if we pretended to inform the learner that each of these will draw a weight or carriage in proportion as they are strong. But notwithstanding this is generally the case, yet we are going to mention what will seem a paradox ; namely, that two horses may be found, one stronger than the

other, and also better skilled in the draft, yet the weaker shall draw a weight, with the very same carriage, the stronger one could not remove! This will be effected, if the weakest horse be the heaviest; if he exceeds his antagonist more in weight, than he is exceeded in strength. We have observed in a former chapter, that the weight re-acts or pulls back the horse, as much as the horse acts upon the weight to pull it forward. Now the horse has two sources of power in drawing the weight along; his strength, which gives him velocity, and his weight, which added gives force; and it is evident that the horse which hath both in the greatest proportion, will draw the heaviest weights. If we should imagine both horses raising an equal weight from a deep pit, and this weight still increased, so as to overcome their strength, it is plain that the lightest horse would soonest be drawn in. We have several instances in ordinary practice, of the great benefit of increasing the horse's weight,

weight, to promote his draught; for in many places, horses employed in turning a mill have a small load laid upon their backs, which, though it takes away something from their velocity, adds to their weight, and consequently increases their force.

BUT supposing the strength, skill and weight of two horses to be the same, all the difference then in their drawing the same weights, will arise from the commodiousness of the machine, in which they draw. If the load they are to drag after them be breast high, they can draw it with much greater ease than if it lay along the ground. They can, for instance, draw much greater draughts, if the weights are laid upon a sledge as high as the horse's shoulders, than if the same weights were laid upon a low sledge on the ground. For in the first case, the column of their bodies acts directly against the weight, in the latter it acts obliquely; and we have shewn before, that

that the more directly this column can act, the greater is its force. Even in either going up hill or down hill, the sledge breast high is more commodious than that laid low. For if the low sledge is dragged up an hill, it is plain that it will be then lower, with respect to the horses, than it was before, and consequently they will be obliged to draw it more obliquely upwards, than when they drew it along the plain. If on the contrary, the low sledge is drawn down an hill, it will then be higher with respect to the horses than when on the plain, and therefore their power of drawing it will be greater; but in going down an hill, its own gravity conspires with the draught, and will also help the load to descend, so that the horses in this case are permitted to exert their greatest power where there is the least necessity; they can draw the low sledge down hill with all their power, when by the natural descending of the load, they are not permitted to exert it.

This doctrine however, simple as it is, is different from what is usually taught by mechanists, upon this subject.

SLEDGES were probably the first machines used in carrying loads; we find them thus employed in *Homer*, I mean in the original, in conveying wood for the funeral pile of *Patroclus*. There are some countries also, that preserve their use to this day. However, men early began to find how much more easily a machine could be drawn upon a rough road, that run upon wheels, than one that thus went with a sliding motion. And indeed, if all surfaces were smooth and even, bodies could be drawn with as much ease upon a sledge as upon wheels; and in *Holland*, *Lapland*, and other countries, they use sledges upon the smooth surface of the ice; for as every surface upon which we travel, is usually rough, wheels have been made use of, which rub less against the inequalities than sledges would do.

In

In fact, wheels would not turn at all upon ice, if it were perfectly smooth, for the cause of the wheels turning upon a common road, is the obstacles it continually meets. For if we suppose the wheels to be lifted from the ground, and carried along in the air, the wheels in this case would not turn at all, for there would be nothing to put any part into motion rather than another; in the same manner, if they were carried along upon perfectly smooth ice, they would meet nothing to give a beginning to the circulatory motion, and all their parts would rest equally alike. But if we suppose the wheel drawn along a common road, then the parts will receive unequal obstructions, for it meets with obstacles that retard it at bottom, therefore the upper part of the wheel, which is not retarded, will move more swiftly than the lower part, which is; but this it cannot do, unless the wheel moves round. And thus it is, that the obstacles in the rough road cause this circulatory motion in the wheel.

THIS

THIS rotation of the wheels about their axle, very much diminishes that friction which always attends the weight's being drawn along upon a sledge; and this in so great a proportion, that according to *Helsbam*, a carriage drawn by four wheels, will be drawn with five times as small an effort as one that slides upon the same surface in a sledge. Still more to diminish the friction in wheel carriages, a countryman of our own hath found out an expedient, whereby the axle, contrary to what is usual in most carriages, is made to turn round, and its gudgeons or ends, instead of pressing against the boxes as in common wheels, are made to bear on the circumference of moveable wheels; so that by this contrivance, a number of parts are made to roll one over the other, which slided before: such wheels, from their thus diminishing the friction, are called friction wheels. We shall enter no farther into their theory or uses; the single inspection of the machine itself would

would throw more light upon the subject, than we could do in pages.

THUS we see how much a wheel carriage affords the horse in drawing, superior to a sledge or any other machine without wheels. Now if we compare wheel carriages with each other, and we desire to know whether large or small wheels are best in a machine; the answer will be, that large wheels are easiest for the horse, but small wheels safest for the rider. A large wheel has a double advantage over a small one, either in surmounting obstacles, or in depressing them. To prove this, let us suppose two wheels, (fig. 35.) A and B, the one large, the other small. As the circumference of both may be considered, like all other circles, as composed of a number of right lines; we may suppose both endeavouring to overcome the obstacle C, with the spoke of either considered as levers, the large wheel with a lever equal in length to Bg, the smaller with
a lever

a lever equal to F g. But the longer the lever, the greater the moving power is increased; it is evident therefore, that the horse drawing at D B, where the lever is long, will have far greater power to overcome the obstacle, than if he drew at F E, where the lever is short, and therefore the larger wheel has the advantage. The horse will draw such a wheel with greater ease over the obstacle, or press the obstacle down into the earth with greater force. As wheels cannot always run upon hard ground, but must frequently meet with holes, in which they partly sink; in this case also the large wheel will have the advantage over the small, for it presses a larger surface upon the sinking earth, and it will not therefore sink so deep; thus a man can easily thrust his finger into soft clay, but it will give more resistance, should he attempt to thrust his fist.

LARGE wheels have the advantage of small wheels, in having less friction round

round their axles; for if the small one turns an hundred times in going over a certain piece of road, the larger wheel will not turn by any means so often to travel the same length, and the less the wheel turns, the less will the friction be. And this frequency of turning required in small wheels, as also the greater obstacles they continually meet with, is the reason why they are more frequently out of order, and stand in need of repair much oftener than the large.

LASTLY; large wheels have the advantage of small wheels, by better directing the load against the column of the horse's body, either in going up or down hill. If the horse draws the load up hill, the wheels being large, raise the weight, more directly to be acted upon by the column of his body; if the horse goes down hill, the wheels being large, raise the weight high above the horse's power, and consequently thus diminish his power; but then it is at
a time

a time when he hath least occasion to make use of it, for the load in some measure will then descend of itself*.

THUS in almost every instance, with respect to the draught, large wheels are preferable to the small, and therefore we necessarily expect to find all our coaches, waggons, and other four wheel carriages, have the fore wheels as large as the hinder. If a waggoner is asked the reason why this is not so, his answer is, that by making the foremost least, the hinder wheels thus drive on the first. This however is by no means the true reason; the fore wheels are made thus smaller than the hinder, both for the conveniency of turning with greater ease, and because the carriage being thus sup-

* I take no notice here to the young student, concerning the preference of small wheels in going up ascents, for which there are some pretended demonstrations; my reason is, that those demonstrations are false.

ported upon unequal wheels, it will be in less danger of overturning. They thus also avoid cutting the braces or straps, by which the horses draw. In heavy waggons however, where the necessity of turning is but seldom, and the danger of overturning scarce any, and the braces are removed at a distance, if the fore wheels were made as high as the hinder ones, it would be so much the better. As it is however, waggoners should lay the load equally upon all the wheels; but on the contrary, they are universally found to lay the greatest part of the load upon the two fore wheels, which not only makes the friction greatest, where it ought to be least, but also presses the fore wheels deeper into the ground than the hinder ones, which we observed before, were most apt to sink, without this additional disadvantage. The only danger that might result from the waggon's being evenly loaded would be, that in drawing up steep hills, the load might be apt to fall backward, and thus

thus tilt up the fore wheels of the carriage. This might easily be remedied, by a machine placed under the fore part of the waggon, which, upon the carriage's going up hill, might be so contrived, as to let sink the foremost end of the load, and thus keep the whole still even.

It now only remains to say something with respect to the breadth of the wheels. Some have insisted that broad wheels are best for the draught, and build their assertions upon theory and experiment; others, on the contrary, and the whole body of carriers in particular, taught by experience, give the preference to the narrow. The determination of this dispute must be left to others, more skilful in waggons and broad wheels than I can pretend to be; a word or two will suffice. If we suppose the broad wheel to have three times the breadth of the narrow wheel, it will meet with three times as many obstacles by the way, but the narrow wheel will sink three times as deep; the question therefore is, whether

three times the obstacles at the surface of the ground, is greater or less than three times the obstacle beneath the surface? The answer will be, that the three obstacles at the surface will be much easier removed than the three beneath it; for they lie lighter, and are sooner thrust out of the way. But however this may be in theory, in experience it is otherwise; for the narrow wheel does not sink three times as deep as the broad, because the earth hardens by the pressure under it, as it descends; on the contrary, the broad actually encounters three times as many obstacles. However, though the latter may not be so good for the carriers, yet they are certainly good for the roads, and therefore for the public in general. Private disadvantage must ever be postponed to public utility.

THUS much will suffice upon the principles of mechanism in general; to enter upon a description of particular artificial machines, would be both uninteresting, and indeed foreign from the
purport

purport of a science, that pretends only to explain the wonders of nature. To give any idea of machines, plates would be requisite, and even such would make but an obscure impression. The best way to understand the arts of machinery is, to view them as they really exist, to visit the shops of artificers, or the yards where great works are carried on. To be a good mechanist would take up a whole life, and the art is rather perfected by practice than theory. For instance, theorists have long debated what is the proper angle of obliquity, by which the sails of a wind-mill are to be regulated and fixed, and whether they are to be elliptical, or on the contrary oblong: practice at present seems to follow the opinions of neither side; the sail is made to bosom upon the wind, like the sail of a ship. In short, the principles of mechanism may be learned in books, the art must be acquired by experience. Several volumes have been written upon the subject; should we, upon the present

occasion, enter into a description of but a few machines, we must necessarily say either too little, or too much: too little to give the learner an adequate idea of any of them; too much for an elementary treatise upon natural philosophy.

C H A P. XVIII.

Of Friction and the Resistance of Fluids.

THROUGH the whole former theory of motion, we have supposed that machines did not rub against each other, and so interrupt their mutual workings. We supposed that all the planes on which they moved were even, all the levers inflexible, and that the air gave no resistance : but in nature this is not the case; for all these are impediments which it is impossible wholly to overcome. As we have established the theory however, it will now be easy to consider the nature of these resistances, how far they diminish motion, and to make an abatement in proportion, in the working of any machine, or in the collision of one body against another.

HOWEVER plane and smooth bodies may appear to our sight, yet if we examine their surfaces through a microscope,

scope, we shall discover numberless inequalities. These inequalities are the causes of friction in two bodies, that move in contact with each other; the little risings in one body stick themselves into the small cavities of the other, in the same manner as the hairs of a brush run into the inequalities of the coat, while it is brushing. If the bodies slide one over the other, the little risings in one body in some measure tear, or are torn by the opposite depressions into which they had been driven, so that sliding bodies move with difficulty. If, on the contrary, they roll over each other, then the small risings fall perpendicularly each into its socket, and are lifted out of it again, without any rupture in the surface of either body whatsoever,

IT is no easy task to measure precisely the quantity of motion that any two bodies will lose by thus rubbing one over the other, even though we knew that the workman had polished both the
surfaces

surfaces to the highest pitch of his art; though we knew the dimensions of each surface, and still more, though we knew the exact pressure in each body; it is almost impossible, I say, in this case, precisely to tell how much the friction between these two bodies will alter any former theory. Thus for instance, suppose I throw a smooth cord over a fixed pulley, and hang a pound at one end of the cord; then if I have a mind to out-balance this, I hang a pound and a grain at the other end of the same; but though in theory, this pound and grain would out-balance the other, yet in fact it will not; it will not stir the former, because the friction of the cord is yet to be overcome. If I then ask what is the precise additional weight requisite for overcoming this friction, all the answer a philosopher can make is, that he has no general rule for this, and that he cannot tell what weight will suffice, till he tries the particular case. It is true, he may guess pretty nearly, but still it will be but guessing.

If

IF I am to guess at the quantity of motion that is lost in any machine, by the rubbing of two bodies one against the other; I must first consider the roughness or smoothness of the surface; I must next consider how great the force is, that presses the two rubbing bodies together; I must then find out with what swiftness they move one over the other; and lastly, I must take into my account the largeness of the two surfaces that are thus rubbed together.

WITH regard to the smoothness of the two rubbing bodies, it is very evident that the smoother they are, the less will be the friction, and for this reason; in all machines where there is much friction of the parts, such as in the nave of a wheel, in the axle of a pulley, and such like, they are greased with oil to fill up the cavities and risings, and thus to facilitate their sliding with ease, surface over surface.

WITH

WITH regard to the pressure of the surfaces against each other, all philosophers allow, that where the surfaces are pressed hardest together, their friction will be greatest; the friction, for instance, in the nave of a waggon wheel, where the pressure is proportioned to the load, will be greater than the friction in the wheel of an ordinary post-chaise, that carries much less weight, and the surface will require to be smeared oftener. Now suppose it should be asked, if we double the pressure, whether we still increase the friction also in the same proportion? It is not easy to answer this. *Amontons* of the academy of sciences of *Paris*, and *Desaguliers* our countryman, think in the affirmative, and say, that friction constantly increases with pressure, and that double pressure will cause a third part more friction. Thus for instance, if there be a machine, in which to overcome its friction, will require two mens strength, if we double this load, it will, they say, require three men to overcome

the friction; if we double that again, it will require six men; and so forth. To support this assertion, they bring several experiments, tolerably exact, and very plausible.—Most philosophers had come into their sentiments, till *Muschenbrook* of *Leyden*, and *Camus*, by contrary experiments, induced them to suspend their assent. They have shewn, by more accurate preparations, that by the same pressure, some bodies have greater friction than others, that the friction will be very different if the surfaces are smeared with oil, or if with tallow, or with water. Thus the experiments of these two latter philosophers differ greatly from the preceding; but unfortunately, they differ as much from each other. All therefore that we can generally conclude from the experiments of each of them is, that friction is increased the more the surfaces are pressed together; but we cannot exactly tell, if by increasing the pressure, the friction increases in a similar proportion.

To

To bring our conjectures nearer to certainty, in measuring the quantity of motion lost by friction, we must next consider the swiftness with which the two surfaces are rubbed together. *Muschenbroek* assures us, that from several experiments he has made (though he does not tell us what those experiments are) the friction increases in proportion to the swiftness with which the surfaces glide over each other; *Nolet* is of the same opinion; they only differ in this, that the former thinks increasing the swiftness to a great degree, will still increase the friction the more; the latter supposes, that the friction hath its bounds, and after the surfaces come to a certain degree of swiftness, though their velocity be then increased never so much, yet there will be no increase of friction. Should we ask the opinion of a common carrier of common understanding upon this subject, he would affirm the very contrary of what the two last mentioned philosophers have

have asserted. He would say, that if his wheels were well greased, the swifter they went, the easier they were upon the horse, and the less would be their friction: *Euler* of *Berlin* is of the very same opinion. In fact, let us compare the inequalities of one surface going swiftly over the depressions of the other, to a chariot wheel, drawn violently over the inequalities of a stony road; we have often seen that before it well could get to the bottom, in descending from the top of one stone, it is drawn up to the top of another, so that in fact, it had thus a less obstacle to encounter, than if drawn slowly along; for thus it scarce had time to sink between the two obstacles, with the whole force of its gravity. It is just thus in the case under consideration; the swifter the surfaces move, the more their mutual pressure is diminished, and consequently, the less deep will the inequalities of one surface insert themselves into the depressions in the other. The truth of this theory *Euler* has

has confirmed by experiment, as may be seen in the *Memoirs of the Berlin Academy* for the year 1748, that upon the whole, the swiftness rather diminishes than increases friction.

LASTLY, in estimating how much a machine is retarded in its workings by friction, we are to consider the largeness of the two surfaces that rub each other; and to first thoughts it would seem, that as the inequalities of the surfaces are the principal cause of friction, if we augmented the extent of these inequalities, we should also augment the friction; so that if the surfaces were doubled, the friction would be doubled in the same manner; if the surfaces were made three times as great, the friction would be made three times as great also. However, this is by no means the case, the increase of friction bears no degree of equality to the increase of the surface; so that I may often make the surfaces ten times as large, and yet the friction shall
not

not for all this become four times as great. *Desaguliers* and *Amontons* are of opinion, that we may increase the surfaces to what degree we please, and yet their friction would still remain the same. For, said they, to make the inequalities of a large surface, sink into the depressions of the opposite surface, will require a force of pressure, in proportion to the number of the inequalities. The number of inequalities is greatest in the largest surface, and therefore, if the pressure in the large surface, be no greater than in a small surface, the inequalities of the large surface will be pressed in with less force, and so not sink so deep as they will in the small. In two bodies therefore, pressing each other in large surfaces, though the pressure is more diffused, yet it is not so deep; and consequently, continue they, the resistance they give to each other's motion will not be increased by merely increasing the surface only. This theory, as we may easily conceive, would have but few partizans, if it were unsupported

ported by experiments. Feeble experiments were produced, to support a feeble theory; but both gained strength when united, and convinced many, whom either, singly, could not persuade. *Muschenbrook* was the first who opposed this erroneous theory, and that with an experiment that was incontestible. He asserted, that by increasing the surfaces of two bodies sliding over each other, the friction was also increased. For, continued he, if we take two small pieces of a deal board smoothed and polished, one piece a foot long and an inch broad, the other a foot long and two inches broad, and if we lay the same loads upon both, taking into consideration the weight of the boards themselves, the largest, he assures us, will be always found to move with greatest difficulty; a proof of its receiving greater obstacles from friction. Thus it appears, that increasing the surface will increase the friction, however in no very considerable degree; for it often happens that the friction is not

thus increased a fifth part greater, when the surface becomes twice as great.

IN a word therefore, in estimating the best manner of diminishing the friction in any machine, if we suppose all the parts smooth and well oiled, it will be found, that the less the pressure is upon the rubbing surfaces, or in other words, the less the load lies upon the parts that move, the less will the force of the machine be retarded by friction; the less extensive the rubbing surfaces are, the less also will be the friction. But then this consideration of the surfaces, is by no means equal to that of the pressure: for if we double the pressure, we shall go near to double the friction; on the other hand, if we double the surface, this will give but a very inconsiderable addition to the friction, so that we may rest assured, that a doubled pressure produces more friction than a doubled surface. Lastly, the swifter the bodies move over each other, the less will they rub,

rub, and therefore friction will be more diminished in a machine that goes fast, than in one that moves slow.

FRICTION is to be taken into consideration in the working of every one of the mechanic powers, and as it is incommodious in some, so it is beneficial and convenient in others; the lever, the pulley, and the axle in the wheel, are retarded by this; while, on the contrary, our operations by the wedge and screw, would be impossible to be performed without it. For in the wedge, when it is driven into the cleft by the force of the hammer, if it were not kept in the cleft by the power of friction, it would be driven back again by the resisting power of the timber. In the screw, when we had pressed down a resisting body, by the excess of power we had over it, this body, upon our pressure being removed, were it not for the force of friction, would drive the screw back again, and we should see the screw

turning up again, with much greater velocity than that with which it was forced down.

THE theory of friction, if perfectly understood, would be of infinite service to society; for then we might calculate with the greatest exactness, the force with which any machine would move, and the number of hands it would require to work it. Besides this, geometers might make their calculations on several mathematical problems with greater precision, as in Brachystochrones, Isochrones, and such like; this would be a great pleasure to them, though of little advantage to society. Some of our own countrymen have taken pains, to ascertain how much friction some woods have more than other woods, and some metals more than others. The friction is found to be greater between small deal boards, than oak; it is much greater between plates of lead, than plates of brass.

It were indeed to be wished, that if possible, this part of natural philosophy were cultivated with more assiduity; and as we have tables for shewing the different densities of bodies, so we might have tables for shewing their different frictions also. It must be owned however, that a work of this kind would require assiduity in the experimenter, and great accuracy in the measuring instrument. Instruments have already been contrived for this purpose, but most of them too faulty to be built upon. *Muschenbrook's* instrument for measuring friction, is reckoned the best; to him we refer the reader for its description. He calls it a Tribometre, a name compounded ungrammatically enough, but it means a measurer of friction. The great defect of this instrument is, that a part of the force employed in turning the disk, is spent in twisting the cord that holds it.

BESIDES the obstructions all machines

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find

find from friction against each other, there is another by no means to be disregarded, which they receive from the air. That the air gives great resistance to bodies passing through it, every one must have experienced; and that this resistance is increased, the swifter the body is moved, and the larger the surface is expanded, which is carried through it. Who does not know, that if I spread a fan, and move it too and fro, it will find more opposition from the air, than if I furled it up, and only brandished the sticks. A man on horseback, if he goes in a calm day, with an easy gentle motion, will perceive no wind; but if he puts the horse upon a full gallop, it will appear to him as if he rode in a storm; for he passes successively from one body of air to the other, and whether he dashes against the air with violence, or the air dashes with violence against him, as in an high wind, it will, with respect to his sensations, have the same effect,

Now

Now should I desire to know the exact resistance of the same air, upon two bodies of exactly the same kind, but different weights; suppose, for instance, how much a leaden bullet of two pounds, would be resisted more than a leaden bullet of one. This question cannot be resolved exactly, without the geometer's help. I may answer in general indeed, that the bullet of two pounds will meet as much more resistance from the air, as its surface is greater than the surface of the other. But to determine this is not so easy, as some may at first imagine. For to calculate exactly how much resistance the air will give to a body opposed to it, we must know exactly how much is the tenacity of the air itself, that is, how much its parts stick together, how far its parts are elastic, how far its parts close round the body that passes through them, and lastly, what part of its surface the moving body presents to oppose it. We know not enough of the air to determine

these points with any precision; the discussion of each particular makes the most abstruse parts of speculative geometry. *Huygens* discovered by experiment, that in bodies moving through a fluid, if the body moved twice as fast, it met with four times as much resistance as before; if it moved four times as fast, it met with eight times as much resistance, and so on. This experiment he attempted to prove by theory, (for theory most usually follows experience) but finding himself unequal to the task, he left it for *Newton* to perform. *Newton's* demonstrations are too abstruse to be inserted here, and indeed they do not seem established upon a basis equally firm, with the rest of his discoveries; for this reason they have been controverted by some of the greatest geometers of the age. *Pemberton* has undertaken to explain the doctrine of *Newton* upon this difficult subject, as follows; though we must observe that the reader will by no means see *Newton* himself through the medium of this
expla-

explanation. "The principal resistance which most fluids give to bodies, arises from the inactivity of the parts of the fluids, and this depends upon the velocity with which the body moves, on a double account. In the first place, the quantity of the fluid moved out of the place by the moving body in any determinate space of time, is proportionable to the velocity with which the body moves; and in the next place, the velocity, with which each particle of the fluid is moved, will also be proportional to the velocity of the body: therefore, since the resistance which any body makes against being put into motion, is proportional both to the quantity of matter moved, and the velocity it is moved with; the resistance which a fluid gives on this account, will be doubly increased, with the increase of the velocity in the moving body; that is, the resistance will be in a two-fold or duplicate proportion of the velocity wherewith the body moves through the fluid." That,

as

as we said above, if the body moves twice as swift, it will meet four times the resistance. Such will be the case of a body moving through a non-elastic fluid; but the air is elastic (as we shall see when we come to treat of its properties) and therefore it must resist in a different manner. "If the elastic power of the fluid," continues *Pemberton*, "were to be varied, so as always thus doubly to resist the velocity of the moving body, it is then shewn (by *Newton*) that the resistance derived from elasticity would increase in the same proportion, insomuch that the whole resistance would be in that proportion, excepting only that small part which arises from the friction between the body and the parts of the fluid. From whence it follows, that because the elastic power of the same fluid does in truth continue the same, if the velocity of the moving body be diminished, the resistance from the elasticity, and therefore the whole resistance

“ance will decrease in a less proportion
“than the duplicate of the velocity;
“and if the velocity be increased, the
“resistance from the elasticity will
“increase in a less proportion than the
“duplicate of the velocity; that is, in
“a less proportion than the resistance
“made by the power of inactivity of
“the parts of the fluid.” Upon the
whole, as this is a subject that more
particularly belongs to mathematicians,
with them we shall leave it; only ob-
serving, that by a train of reasoning,
Newton has proved that a globe moving
through a fluid, such as air, that closes
behind the body as it moves, suffers
but half the resistance which a cylinder
will do of equal diameter, if it moves
endways; and in general, let the shape
of the bodies be ever so different, yet if
the surfaces with which they cut the
air be equal, the bodies will be equally
resisted. Thus, in the motion of an
arrow, if the surface, with which it
cleaves the air end foremost, be as small
as

as that with which a bullet cleaves the same, it will meet with no greater resistance.

WE have now seen, though obscurely enough, that if a body moves twice as fast, it will meet nearly four times as much resistance from the air, and that some sorts of surfaces are more resisted than others. But this difference of surface however, causes but very little alteration in the air's resistance; so that physically, though not geometrically speaking, we may say, that the greater the surface of a body opposed to the air, the greater will be the resistance. A body which has twice the surface of another, when moved along, will strike twice as many columns of air in its way, and consequently will meet with twice the resistance. Bodies however that have a great deal of weight under a small surface, will meet with a very trifling resistance, compared to the force with which they move. For to make this very plain, suppose

suppose an hollow paste-board globe were shot from the mouth of a cannon, the resistance it would meet from the air, would be in proportion to its surface, as we said before. But now suppose it to be filled with an hundred leaden bullets, each as heavy as the globe itself, and shot forward; the resistance it would meet from the air, would be no greater than before; but there would be an hundred bullets within it, that met with no resistance from the air whatsoever, therefore the whole of the globe would move forward with all its parts, an hundred times less resisted than when it was hollow. Thus, though light and heavy bodies meet a resistance great or little, as their surfaces are large or small, yet the power that heavy bodies have of overcoming this resistance, is much greater than that of the light. The force that has driven the heavy body forward, was impressed upon all its parts, the force of the air that resists it, is merely impressed upon the parts of the surface alone.

FROM

FROM all this therefore it appears, that the smallest bodies having the greatest surfaces in proportion to their weights, are most resisted in their progress through the air. From this it appears, that a body reduced to powder can be thrown but to a very small distance, the resistance being great, because the bodies in motion are but small. A fowler who shoots with small shot, is sensible that the charge can carry it but a short way, if compared to the distance to which a bullet would go. Should the surfaces of all the grains be united under one general surface, and the whole be melted down into a single ball, this would proportionably diminish the surface, this would diminish the air's resistance, and this would carry the charge to a more distant mark. From this it appears, that a body thrown from the hand will go farthest if it does not divide by the way; for its division multiplies the surfaces, and the surfaces increased, so also is the air's resistance.

THUS

THUS far we have speculated, as if the body to be moved was only in motion, and the air was quite still and motionless. This however it seldom is; we always perceive some wind, and there is almost ever enough to point the weather-cock. In this case therefore, a body moving against the wind has a double resistance to overcome, its own inertness to motion, and also the motion of the air. For this reason, the motion of the body will be retarded in proportion as both these resistances are increased: if a race-horse should carry his rider with as much rapidity against a strong wind as he does in a calm, the jockey would not be able to endure its impulse; but this he is unable to do.

FROM all that has been said of friction, and a fluid's resistance, we see how vain it is to expect that a body will move for ever; since if we could suppose an infinite force to put it into motion, we here see a resistance continued infinitely
• to

to controll it; and where two forces are equally infinite, they will destroy each other. We might perhaps, upon the principles of mechanisim, contrive such a machine as would move, if unresisted by external pressure; this we must suppose, if we allow the first principles of philosophy, which take it for granted, that all motion if once begun, would, if uncontrolled, continue for ever. A pendulum, if its machine never required winding up, would in this sense be a perpetual motion; but such machines for pendulums have never been hitherto discovered, and they might answer but few useful purposes upon the discovery. In fact, the perpetual motion is now scarce sought for by any; we even hear the name now little used, except in the mouths of those half witted people, who are said by the vulgar to have gone mad with too much learning.

CHAP. XIX.

Of Water.

AMONG fluids, water seems to claim the first place; its properties are more obvious than those of air, for even the ignorant allow water to be a fluid substance, but few of them will grant air, which they do not see, to have any substance whatever. Its services to mankind also give it the preference to other liquids; and are well known; but it is not our business to declaim upon its uses; let us as far as we can explain its nature.

HOWEVER fluid water may seem, and unresisting to the touch, yet few bodies can be found, the parts of which are more hard. If it be put into a globe of metal, and the hole be then soldered up with care, no art, no power nor force on earth can press it into a smaller compass than it occupied before. We

can condense metals into a smaller compass, hard as they appear, but water cannot be condensed. If our attempts be prosecuted with violence, the metal, and not the water, will give way; for the fluid will drive through the pores of the globe, and stand like dew upon its surface.

NOR is the hardness of the parts of water less proved, by the pain it gives upon striking its surface pretty smartly with the palm of the hand. Many also who have leaped into water, from the battlements of high bridges, have been cruelly undeceived with regard to the unresisting qualities of this fluid; the shock the body sustains in this rude experiment, is inexpressibly violent. But it is no way extraordinary that the body should feel pain in the conflict; for if a leaden bullet itself be discharged from a gun, into the water, this seemingly unresisting fluid will actually flatten the ball.

BUT

BUT whatever force water may have while its parts remain together, is nothing, if compared to the almost incredible power with which its parts are endued, when they are reduced to vapour by heat. Those steams which we see rising from the surface of boiling water, and which to us appear so feeble, yet, if properly conducted, acquire immense force. In the same manner as gunpowder has but small effect, if suffered to expand at large, so the steam issuing from water is impotent, when it is permitted to evaporate into the air; but when confined in a narrow compass, as, for instance, when it rises in an iron tube shut up on every side, it then exerts all the wonders of its strength. *Muschenbrook* has proved by experiment, that the force of gunpowder is feeble, when compared to that of rising steam. An hundred and forty pounds of gunpowder blew up a weight of thirty thousand pounds; but on the other hand, an hundred and forty

pounds of water, converted by heat into steam, lifted a weight of seventy-seven thousand pound, and would still lift a much greater, if there were means of giving the steam greater heat with safety; for the hotter the steam, the greater is its force.

UPON this principle of the irresistible force in the steam of boiling water, one of the most forceful and noble machines has been completed in our days, that ever appeared among the inventions of mechanism. It is called the steam engine, a machine by which the force of steam is made to answer all the purposes of the united strength of hundreds. The force of steam may thus be applied to the working of excessively large machines, which would require a most expensive share of bodily labour to manage. The same force may be applied to the raising immense weights, to the fatigue of which, animal strength would be unequal; in short, wherever great force and

and perseverance are wanted, these engines can effectually lend their assistance. The most usual purposes however, to which the force of steam has been applied, are in working pumps to clear the water from mines, or raising it to proper heights for the supply of cities. Philosophers were long acquainted with the great force of steam, and *Papin* actually contrived an instrument, somewhat resembling the steam engine now in use, but in miniature. But yet this instrument of *Papin's* contrivance, was only a subject of speculation to the curious; though long before him the marquis of *Worcester* had asserted the uses to which the force of steam might be converted, in a machine for raising water. Still however neither the principle nor its utility were generally known, so that the honour of the compleat discovery and use of this machine, which is incontestably the greatest production of the present age, was reserved for two obscure but sensible citizens of plain under-

standing, which is ever the best. Mr. *Newcomen* an ironmonger, and Mr. *John Cawley* a glazier, inhabitants of *Dartmouth*, are the persons to whom we are indebted for this surprizing engine, which has been of more service to mankind than the invention of algebra. The principle on which it is founded is only this: Instead of working an enormous water pump with bodily labour, the steam may be so applied as to drive up the arm of a pump rod, and the power of suction will serve to draw it down again; so that the arm, thus alternately raised and depressed, lifts the water in the pump, which flows out at top, at the rate of above three hundred and twenty hogheads in an hour.

BUT to give the learner a superficial idea of this machine, let us imagine a common pump prepared, such as we every day see, and that we want to move the handle of this pump upward, by the force of steam only. In the first place, let

let us suppose matters may be contrived so as that the handle, or something joining to it, may go into the barrel of a gun, or some such hollow tube, set upright over a cauldron containing boiling water. Next let us suppose, that the steam may be let into the tube at pleasure, through the touch-hole; now as the fire begins to dilate the steam, a part of it will enter the tube at the touch-hole, and this will press up the pump handle which fills the tube very exactly, and would drive it quite out at the mouth, but that by the time it gets near the mouth of the barrel, there is a contrivance by which a little cold water is spouted into it, and this effectually destroys the steam at once; and thus it sinks to the bottom of the barrel and leaves it perfectly empty. The air therefore without will now come into play, and press down the handle again into the empty tube, into which no steam is permitted to enter, by a contrivance that stops up the touch-hole below;

but when the handle is thus pressed down, the touch-hole below is again opened, and new steam entering again, presses the handle upward; when the handle comes toward the top, the steam is again cooled and destroyed as before, and the handle again is pressed down by the external air; and thus it is alternately pressed up and down, and works the pump with unwearied assiduity.

SUCH is the force of vapour, and a part of the use to which it may be applied. But although the stronger the fire, the greater the force of the vapour, and the greater its quantity also, yet no fire how fierce soever can give water above a certain degree of heat; for as soon as it boils, we may increase the fire in the most vehement manner imaginable, yet the water will not get one whit hotter than before. The greatest heat water is capable of receiving, being measured by the thermometer, just amounts to two hundred and twelve degrees; at that pitch
it

it begins to boil, and increasing the fire afterwards serves to promote its evaporation, but not to increase its heat. However, though it becomes no hotter, yet its power of dissolving the texture of substances thrown into it, is increased by increasing the heat beneath; for by this means, the parts of the water strike with more force upon the parts of the body, and thus sooner destroy their arrangement.

As water begins to boil, it is usually seen to bubble; the less it is pressed by the atmosphere above, the more it bubbles, and in the void it bubbles very readily: if the surface of boiling water be therefore covered with a fluid, which presses like the atmosphere upon it, the bubbling, or as it is usually called, the boiling over of the water will be thus prevented. The more tenacious or gluey any fluid is, the more in this manner it is apt to boil over; however, if any lighter fluid is thrown in which will
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press down the bubbling surface, and thus make an artificial atmosphere, if I may so express it, this will prevent the dangerous effects of the overflowing fluid. Boiling sugar thus is apt to run over; but this is prevented by throwing in a piece of butter, or some such like substance, which spreading, floats upon the surface, and keeps the other fluid from rising.

THE cause of this ebullition in boiling water, the cause of the surprizing force of its vapours when driven off by heat, the cause of the yielding fluidity of its parts; these are utterly unknown, and in this respect we must be contented like geographers, to give the map of a country, without knowing its real productions. Some ascribe the bubbles in boiling water to the air endeavouring to get free, and thus assuming a spherical figure. Others ascribe them to the parts of the water itself, reduced into thin plates by the interposition of the

parts of the fire. For the first, waters purged of their air by former boiling, bubble as much as those which have all their air still remaining; as to the second, the densest liquors bubble least, such as mercury, yet these admit of a much greater proportion of fire between their parts to reduce them to thin plates, than lighter fluids. These, and several other phenomena of this fluid, are all equally inexplicable. Thus we know that water extinguishes fire. Why? *Muschenbroek* will tell us, that the fire consumes and feeds upon bodies, only because they contain a quantity of oil; That this oil, when set on fire, has an heat of six hundred degrees, that the greatest heat of water is only two hundred and twelve degrees, so that water must cool the oil, and so extinguish the flame. This would be a very plausible solution, did we not find that water often makes a fire burn with still greater force, when thrown in small quantities upon it; so that in such a case, water, mixed
with

with this imaginary oil, makes it burn fiercer.

WATER, like every other substance with which mankind are acquainted, is never found simple and unmixed; though it be distilled never so often, yet it will have an earthy sediment at the bottom of the vessel, in which the process is performed. We have an account of the different substances with which it is usually mixed, in *Boerhaave*; but one more accurate still, has lately been given us by *Margraff*, a German chymist. A hundred German measures, or about fifty English quarts of rain water, gave, upon distillation, an hundred grains of a yellowish white earth, a few grains of nitre, and some of common salt. The greatest care was taken to have the water pure and unpolluted, yet still it exhibited this heterogeneous mixture. These salts were evident demonstrations that the same water also contained oil, and therefore if so, it must have been upon that account

account subject to putrefaction. For this purpose, *Margraff* exposed it for some time to the weather, and at about the end of one month, he perceived a kind of internal fermentation, and a greenish substance began to stick to the bottom and sides of the glass, resembling the mantle of a standing pool; its smell was disagreeable, but it was near three months before it was perfectly putrefied; a proof that the oil it contained was in much less quantity, than in the generality of other substances, which rot much sooner. Snow water exhibited the very same appearances, but upon the distillation, rather furnished more earth, and less nitre; a pretty evident proof that nitre is not the cause of the congelation of water into snow, as some have imagined. In short, in this naturalist's experiments, snow water seemed equally foul with that of rain water; contrary to the experiments of *Boerhaave*, and many of our own countrymen, who have taught us to regard snow water as more pure than any other,

SPRING water is generally pure or polluted, in proportion as the earth through which it happens to stream, is impregnated with minerals or salts, which it is capable of dissolving. Those waters which come through or over beds of salt, or layers of ore, take a strong tincture from either, from whence we have spaw waters of different kinds. Those that are strained through a sandy soil, free from saline or metallic substances are much more pure.

RIVERS in general furnish pure water in proportion to the purity of the fountains by which they are fed, or the nature of the soil through which they flow. The largest rivers have in general the most unpolluted streams; the *Indus*, the *Rhine*, and the *Thames*, all produce the softest and purest waters, most pleasing to the distinguishing palate, and least liable to putrefaction.

As water, when thus mixed with weighty saline and metallic principles, must

must be necessarily more heavy than when perfectly pure; so in many cases, the weight of water will serve to distinguish its purity. The most pure water will in general be the lightest; but we must not depend upon this as a rule, for often a putrescent oil is mixed intimately with the fluid, particularly when it flows over fat and unctuous beds of earth; this in a small quantity mixes with its substance, diminishing its weight at the same time that it increases its tendency to putrefaction.

OF all kinds of water, that in stagnant pools is the most impure and noxious to the constitution. Water serves as a dissolvent to almost every substance that is thrown into it; in this manner salts, metals, plants, ordures of every kind, are all generally mixed together in these places, and make one mass of corruption, equally displeasing to the sense, and injurious to the health.

THIS

THIS water however, may be used in cases of necessity : but there is still a larger store of this fluid, which nature seems not to have allotted for the use of man, I mean the salt waters of the sea. These, as we well know, contain salt in very great quantities, together with a bitumen, perceivable both to our taste and smell ; these salts being much heavier than water, and being dissolved in it, give the contents of the ocean that superior strength and weight which fresh water cannot equal. Where fresh water supports a body of a thousand pounds, sea water will support, all other circumstances the same, one of a thousand and thirty pounds.

HERE again new questions arise, for which philosophy has not yet found a satisfactory solution ; Whence is it that the sea water is charged with saltiness, while that of rivers is mild, fresh, and fit for human purposes ? Some, instead of giving a cause for its saltiness, have offered

offered reasons to shew that it is fit the sea should be salt. Wanting, say they, the motion which rivers have, it would be apt to putrefy by its natural stagnation, but salt preserves all substances from putrefaction, and therefore it preserves the waters of the sea also. This is false: the sea is prevented from stagnating by many causes, as for instance, the tempests and tides give it continual motion; and when sea water actually stagnates, it putrefies like fresh.

Halley rejecting such a puerility, substitutes one of his own: he thinks that rivers wash down all this salt from the earth into the ocean; and that at first, the sea water was as fresh as that of the rivers themselves. This is not true: the ocean is ten times as large as the earth; salt makes a fortieth part of the ocean. If the earth supplied this fortieth part, a fourth part of its substance must thus have been solid salt; but common earth does not furnish a

grain of sea salt from an hundred pounds of it. *Buffon* ascribes the saltiness of the sea, to beds of salt at the bottom of the ocean. An experiment is against him; sea water is saltier at top than at bottom. We must at last therefore be compelled to unite these two causes, and this will bring the matter something nearer to probability; let us then suppose that the sea is salt, from the rivers which continually bring in a store of this mineral with their waters, and from beds of salt lying at the bottom of the ocean, which its waters are dissolving and carrying away.

C H A P. XX.

Of Springs and Rivers.

WERE water always at rest, undisturbed either by the winds or other external pressure, it would corrupt and putrefy. We have already taken notice of its putrefaction in the vessels of the chymist, who exposed it for that purpose, and the same thing constantly happens to those who store up water for long voyages. It loses its transparence, generally becomes first brown, then greenish, and at last turns red; in fact, it always putrefies: but the waters of different rivers have various appearances in each state of their putrefaction, each putrefying less offensively, in proportion as it furnishes a fluid the least polluted with heterogeneous mixtures.

THIS putrefaction is prevented in the natural state of things, by the motion of

the fluid; for we seldom see water running in springs, rivers, or seas, suffer these changes. By constantly rolling onward, it is probable that the fluid still presents new surfaces to the ambient air, and either imbibes a freshening principle from the atmosphere, or deposits its feculent parts upon air, which, like a sponge, is fitted to attract them. However this be, certain it is that running streams and rivers are more pure than such waters as stagnate; so that though we may be ignorant how motion thus contributes to the sweetness and transparence of water, yet we are certain that motion produces these happy effects. The manner how water freshens as it flows, may be hidden from human penetration; the consequences of this motion are obvious to the slightest search.

BUT now it becomes an enquiry equally interesting and curious, to investigate how this salutary motion in
waters

waters has been originally produced; how this circulation of the fluid, which we see carried round our globe, is continued; from whence do springs derive their stores, to furnish rivers with a constant supply; in what manner do rivers flow constantly towards the sea; or how does the sea itself daily swell and sink in tide and ebb, with unremitted alternation?

To begin with the first natural agent in this extensive circulation, we must observe, that the atmosphere has a power of raising waters up into itself in large quantities. We have seen capillary tubes lift water much above its level; we have seen a loaf of sugar, wet at the bottom, suck up the moisture to the very top. In this manner probably it is, that the bottom of the atmosphere resting upon a large surface of water, attracts it up into itself, and becomes loaded with the vapours of the subjacent fluid. This evaporation also is not a little forwarded

by the beams either of the sun, or the heat which we know to be enclosed within the bosom of the earth; these dilate and increase the surface of the fluid, and consequently promote its ascent. Winds also in the same manner promote this evaporation; they raise the water into waves, and we need not be taught, that the surface of a pond when uneven and wavy is greater than when it is perfectly smooth. All these causes therefore concurring, water is raised in great quantities into the air. If then we suppose this body of water continually raised and rising in the atmosphere, and again falling upon earth; if we suppose those immense stores of fluid, sucked up from the ocean, to be condensed into rain, snows, and dews, and to deposit their stores upon land, here will be a fund sufficient, for the production of springs, and rivers.

LET us now then carry our imagination to the course which a body of these

these vapours may be supposed to take in the air. A sheet of vapour rising from the sea, and waisted by the winds to land, is carried over the low grounds with an even flight, till it dashes against the sides of mountains, or is lifted up by the rising air to their tops. Here the air, which was at first capable of buoying the vapours up, soon becomes too light to sustain them, and also the vapours being condensed into larger drops, by the cold of those upper regions, they sink like rain upon the mountains side, and trickle downwards into the chinky bed of the hills: here entering into their caverns, they gather in those natural basons, overflow, and at last force themselves a passage, and thus single springs are formed; many of these running down by the vallies between the ridges of the hills, and coming to unite, form little rivulets or brooks; many of these again, meeting in one common valley, and arriving at the plain, become a river, the magnitude

of which is generally in proportion to the greatness of the mountain from whence its waters descend. The largest rivers flow from the greatest mountains. The *Andes* of *America*, send forth their *Marañon*; the *African* mountains of the moon, their *Nile* and their *Niger*; the *Alps*, their *Danube* and their *Rhine*.

BUT perhaps it may be thought that evaporation alone, is a cause too slight and insufficient to produce those immense torrents of water, which we have just enumerated. To this Doctor *Halley* replies, (for the present theory is taken from him) that the quantity of water raised by evaporation, is more than sufficient to effect all these purposes. He has attempted to prove, by evaporating a determined quantity of water, with the natural heat it generally sustains, that every ten inches square of water, loses one inch in a day, by evaporation; and therefore, knowing the number of square miles in the surface of the *Mediterranean* sea,

sea, he calculated that it would lose by evaporation, every summer day, fifty-two thousand and eighty millions of tons. This quantity he supposes to be two thirds more than it gains, by the nine great rivers which flow into it. The water of its evaporation alone, would be therefore sufficient to fill three times as many rivers as empty themselves there; and what is true of the *Mediterranean*, may be applied with equal force to every other great reservoir of waters. What they gain by rivers, is not equal to half of what they lose by evaporation; however, if the ocean furnishes in this manner more than enough, it may be supposed to fall back in rains upon its own bosom.

IT would be in some measure unkind to disenchant the beauties of the prospect which this theory presents us. A romantic imagination can form nothing more striking than this unceasing rotation of waters; clouds rise from the ocean, travel till they dash against the tops of the highest mountains,

tains, descend feebly in little streams down their sides, enter the subterranean caverns of the earth, overflow, burst forth in springs, and at length they all assemble into rivers, that carry the united torrent again to its parent ocean. Such speculations are amusing; but as speculations however may be driven too far, so here such a quantity of evaporated water has been contrived in support of this theory, as would, if it fell, drown our earth, instead of refreshing it. Almost every calculator seems to admit, that near one third more water is raised by evaporation, than falls in rain: now what becomes of the surplus, which we must suppose not to fall, is no easy matter to determine. In one part of this theory also, *Halley* assigns as a reason for the *Mediterranean's* constantly receiving a strong current from the *Atlantic* ocean, that the *Mediterranean* loses so much of its water every day by evaporation, and consequently requires this supply. But how can this be the cause of the current in question,

question, since the *Atlantic* ocean loses as much water by evaporation, as the *Mediterranean* itself. The same influence acts equally upon both, and so will cause no difference on either.

WHEN numberless rivulets unite, they form a river, and in every country there seems some region higher than the rest, from whence its rivers seem detached on every side to the sea. *Varenius* the geographer has made an assertion that at first seems extremely improbable, when he gives it as his opinion, that all rivers were originally formed by human toil and industry; that at first they might have been but small canals, but being widened by degrees by the current, they at length have swollen into a *Volga* or a *Po*. Wherever, continues this geographer, we see a flood of water burst from the earth, the water forms no channel, makes no progress towards the sea, but overflows the adjacent country; there forming a lake, which is either constantly

stantly supplied, or soon dried up by evaporation; he also mentions several rivers that have had their channels evidently made by human labour. His observation is curious, though his reasoning be false; and indeed it is extraordinary, that though natural history informs us of many new lakes, that are naturally formed by the burst of waters, it can furnish us with no accounts of rivers made in the same manner.

BUT leaving *Varenius* and his opinions, we must observe, that it is most probable rivers have originally formed their own channels. If the ground over which they flow be very steep, the water must acquire proportionable swiftness; it must thus level the grounds which nature has opposed in their way, the water will by its weight sink itself a bed; and wherever the streams are directed with greatest rapidity, there they will wear the earth most, and become widest or deepest.

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WHEN a river has thus levelled itself a bed, it will then flow more horizontally along, and of consequence will wear its channel more slowly; by this means the bottom will at length be in a state of permanence; whatever it loses by the continual brushing of the water over it, it will gain by the sediment the water naturally deposits wherever it flows. The steepy descent of rivers, when they first begin their course, is generally very great, for it is this which gives them strength to force a passage to the sea; as they flow onward, their descent is less precipitate, they go onward more gently, and their fall is usually very little as they approach the sea. From hence we may conceive a general picture of the windings of a river. When the waters towards their source are rapid and headlong, they move directly forward in a straight channel; but as their descent lessens, their windings increase; and ever, as they approach the sea, assume greater meanders. By this rule, Mr. *Fabry*,
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when travelling through desolate and uninhabited countries, was always enabled to form a probable conjecture of his distance from the ocean; the fewer the sinuosities of the rivers, the farther was he removed from the sea.

THE rapidity of a river's current arises from two causes, the declivity of its channel, and the quantity of its waters; therefore it sometimes happens, that those rivers which have the greatest declivity, are not so rapid as those whose declivity is much less, but whose waters are more abundant. Thus the *Rhone* is by no means so rapid as the *Danube*, and yet its channel is more steepy; for they both arise from the same mountain, but the *Rhone* falls by a shorter, and consequently a more precipitate course into the sea.

IT is not my design to give in this place a geometrical theory of motion of water in rivers; that depends upon principles

ciples not yet explained; though in fact, there is nothing in the writers on this subject, upon which we can depend with certainty. Thus they observe, that the bed of a river may be compared to an inclined plane, and the water as moving down it with an increasing velocity, and consequently the greatest swiftness will be at the river's mouth. But then, say they, in proportion as the velocity is increased by the descent, it is retarded by attrition against the bottom and sides of the canal, and this more than counterbalances the former celerity.

THOSE parts of the stream that are most in the middle are ever the swiftest, because they receive the least obstruction from the bottom and sides to their progressive motion. For this reason, the union of two rivers must encrease their celerity, as it diminishes the number of obstacles which they would meet with if their courses were separate. This also will give the reason why great rivers with

3 a small

a small declivity, are yet more rapid than small rivers whose declivity is very great. The waters of the former meet with less obstruction, and go forward with all their communicated force, while those of the latter continually suffer delay from the sides and bottom of their canals.

WHATEVER diminishes the channel of a river, increases the rapidity of the stream; for the force which drives the water forward still remains the same, and we all know that the same force impressed upon any body, drives it forward with greater velocity, in proportion as the body is less. Thus we see waters going with great rapidity under the arches of a bridge, because the channel is lessened through which they pass.

WE are not to acquiesce in suppositions of geometrical writers upon this subject, that the surface of a river is quite even and plane from one bank to the other.

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On the contrary, upon a sudden inundation, or when the middle of the current is extremely rapid, the middle part rises above the other parts of the surface, sometimes, as it has been found by admeasurement, three feet, though in a small river. The swiftness with which the middle of the current is driven, in some measure destroys its gravity, and thus it rises most, where its pressure from gravity is least. When a river has a backward stream, as in the case of tides flowing up its channel, then the water is highest towards each bank, and lowest in the middle; in the former case, the water of the river resembled a ridge, in this it is hollowed like a furrow.

THE water at the surface of a river, and that at its bottom, are often found to have very different rapidities: if for instance, we dam the surface of a river, by a bridge of boats thrown across it, while the rapidity above is thus diminished, the rapidity of the water running

under the boats, is greatly increased. Those therefore who swim in streams, interrupted in this manner by boats or timber, should not trust to the smooth appearance of the surface, for very frequently, a strong and a fatal current lurks beneath.

WITH regard to the overflowing of rivers, the inundation is generally greater near the source, than the mouth of the stream; for wherever the force is greatest, there will be the most likelihood of the waters bursting their banks, or overflowing them. But we have before observed, that the declivity of the stream is greatest towards the source, and consequently the force of the stream against its banks, must be greatest there also.

THESE hints may suffice upon this subject; but it must not be supposed, that general rules can give us any certain information; a husbandman who, conducted by geometry alone, should attempt to alter

the course of a river, or stop its inundations, would be soon taught, that untaught experience alone, was in this instance a much better instructor. In short, the natural historian is a much better guide on this subject than the mathematician.

C H A P. XXI.

Of Tides.

IT has been the fortune of philosophy to succeed best in accounting for the greater operations of nature, while it is evidently feeble in the minute. In the same manner as we have a satisfactory idea of the planetary system, we have but an obscure account of the changes wrought in our own atmosphere. Thus also, the theory of the flowing of a spring is but uncertain; the theory of the tides of the ocean is nearly demonstrative.

As rivers flow and swell, so also does the sea; like these it hath its currents, that agitate its waters, and preserve them from putrefaction. This great motion of the sea is called its tides. The waters of the ocean have been observed regularly from all antiquity, to swell twice in about four and twenty hours, and as often

often to subside again. This swelling of the sea is most observable upon shelving shores, where the waters retire for near six hours, and leave them quite dry, but soon return again and overflow the sands; and thus the alternate ebb and flow is twice perceived, in the space of something more than four and twenty hours.

IT was an observation also, in the earliest ages of mankind, that this ebb and flow had a constant correspondence with the moon, and that the sea's motions seemed to be guided by the moon's motions. They observed, that whenever the moon came over our heads, one of these swellings of the sea was seen also. They remarked, that whenever it was either new or full moon, the tides were greatest; and on the contrary, whenever the moon was between the new and the full, and shewed us but half its face, that then the tides were least. There are seasons of the year

when, as astronomy shews, the moon is nearer the earth than at other times; they knew that at those seasons the tides rose highest in proportion. They remarked with equal sagacity, that the sun, in some measure, joined his influence to that of the moon; that when the sun and moon were on the same side of the heavens, then the tide rose on that side highest; on the contrary, when these two luminaries were on opposite sides, that the tides then obeying a divided influence, rose less high than before. The sun and moon, as astronomy shews, are more near the earth in autumn and spring than at other times, and therefore the tides obeying their influence, were seen to be greater at those seasons. All this was discovered by the ancients, and *Pliny* has given us a chapter upon the influence of these two luminaries upon the waters of the ocean.

BUT this was only an obscure conception of these wonderful appearances:
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they knew neither the cause of this swelling, nor the manner in which the waters obeyed the lunar influence. The moon came over their heads but once in twenty-four hours forty-nine minutes, whereas they saw the tides actually rise twice in that space, so that here they were perfectly at a loss, since the tides rose twice as often as the cause that produced them. The thorough investigation of these appearances, was left for the sagacity of *Newton*.

WE have often laid it down that attraction prevails throughout all nature; the earth attracts the moon, and the moon attracts the earth towards itself, each in proportion to the quantity of matter contained in either. This being acknowledged, let us see what will happen, when the moon comes directly over any part of the ocean. We have allowed that this planet continually draws the whole earth in some measure towards it; but it will particularly act upon the waters, which

are more at liberty to obey its influence than the solid parts of the earth; so that the waters immediately underneath it, will be attracted up in a heap. Thus we may conceive that part of the ocean as one immense mountain, with its summit pointing towards the moon. But now let us see what will in the mean time be doing on the opposite side of our globe? We said that the waters on the side next the moon, will be more violently attracted, than any other part of the globe, because they are nearest the moon; then of consequence, the waters on the opposite side will be less attracted than any other part of the globe, because they are farthest off from the moon. If they be but feebly attracted, they will be very light, as we know all bodies feebly attracted are; if they be very light they will rise, and all the neighbouring waters will flow to that place; in short, swell into an heap or mountain of waters, whose summit points to the opposite part of the heavens, as the summit on the
other

other side pointed to the moon. Thus does the moon, in once going round the earth in twenty-four hours, produce two tides or swells, and consequently as many ebbs: one tide, when she comes to the meridian, nearly over our heads; another tide, when she is over the heads of our antipodes, on the other side of the globe. These tides must flow from east to west, for they must necessarily follow the moon's motion, which is from east to west. We readily see now, that this double power, acting continually upon opposite parts of the ocean, must agitate its whole mass, and spread the motion not only to the shores of the sea, but drive its waters a considerable way up the rivers also.

BUT all this time, we have made no mention of the share the sun has in these operations. Were this great luminary as near the earth as the moon is, without doubt its influence would be much greater than that of the moon; but this

is not the case; the sun is placed at an immense distance from us, and though its power over the waters of the ocean is very sensibly perceived, yet it is greatly inferior to that of the moon, which though so much less, is so much nearer. Whatever power the moon hath, the sun has a similar power, but in a smaller degree. If the power of both the moon and the sun conspire in raising the tides, they will then have their greatest swell; if both act in such a manner as to lessen each other's influence, the tides will not then be so high. Thus, for instance, when it is new moon, astronomy shews us that the sun and moon are on the same side of the heavens; they will therefore attract the ocean with united force, and we shall have high tides. If again it be full moon, the moon will draw the waters in one direction, the sun will draw them directly opposite, and this we know is the same, as if they both drew the same way, so that this also will make the tides rise

rise high. But now if it be half moon, then the moon makes different tides from the sun, and the ocean obeying a double impulse, swells but in a small degree under either. To have a more thorough knowledge of this subject, it is necessary to understand astronomy; we will only therefore slightly observe, that the tides arrive each day later by forty-nine minutes, because a lunar day is so much longer than a solar day: and let us add, that the greatest swell is not seen while the moon is directly in the meridian of the place, but about three hours after she hath past; in the same manner as we see the waves of a lake have their greatest swell, a short time after the tempest is allayed. Again, when the moon rises directly over the earth's equator, the tides are equally high on both sides of it; but as the moon declines towards either pole, the tides will rise on either side in proportion to her proximity. Towards the poles however the tides are much less than near the equator,

equator, for the moon acts upon the seas of those countries with more remote influence; and besides, the polar oceans being almost continually stiffened into ice, they less readily obey the lunar impulse.

WE said above, that the tides pursued the moon's motion to the west; for this reason therefore the eastern coasts will have high tides, before those that lie more westerly. This is the general law which prevails over all the globe; the navigation of ships to the west, is much more speedy than their return, for they thus in a manner go with the tide.

BUT we must not expect to find this law prevailing in narrow seas, clogged with islands, or altered by contrary currents. The tides are variously affected in their passage through different shoals and channels, and retarded by winding round capes and promontories, that jut out into the ocean. Thus the tide in
the

the *German* ocean, takes twelve hours to come to *London* bridge, where it arrives just as a new tide is raised in the ocean; so that we have the highest tides up the river *Thames*, when the moon makes them least out at sea: for when she rises above the horizon, our tides are least, when in the open ocean they are greatest. In short, if this general theory be well understood, there are few particular cases that will not find an easy solution. Thus, if it be demanded why the *Caspian*, *Mediterranean*, and *Baltic* seas have scarce any tides, it is easy to reply, because they have no considerable communication with the ocean. The less extensive the surface, the less will be the tides; their's is not the hundredth part of the ocean, and their tides will be therefore in proportion.

As the moon's influence is so strong upon the watery fluid that covers the face of our globe, it must have also an equal power over the aerial fluid that

that furrounds it, and will consequently produce tides in the air. Many have thus accounted for the trade winds, that blow continually in the same direction with the ocean, from east to west. But as the air is attracted only in proportion to its quantity of matter, and as that is but very small in proportion to the space it occupies, these aerial tides must be imperceptible to sense, and they can produce no alteration here below.

PHILOSOPHERS have not been content with thus accounting for the tides upon earth, but they have given also a theory of the tides in the moon. If the moon, say they, can raise water ten feet upon earth, the earth will raise water an hundred and ten feet upon the moon; but as the moon has always the same face turned to the earth, its waters, say they, will ever remain at the same height, and therefore all the tides it perceives must be

be occasioned by the sun. But no matter for the tides in the moon; it is very well if they have satisfactorily explained the tides upon earth.

CHAP.

C H A P. XXII.

Hydrostaticks

IN almost every physical speculation, wherever experiment can reach, the subject admits of illustration; wherever that is denied, the reasonings are but vain and conjectural. Thus we are ignorant of the form of the parts of which water or any other fluid are composed, because we can make no experiments which may reduce these subjects into the primary particles of which they are composed. Thus, if we reduce water, by evaporation; to the smallest parts our senses can distinguish, yet if we examine any of these with a microscope, the little spherical drop will be found as fluid as the water in the vessel from whence it arose; the minute drop hath its smaller parts, which give it fluidity; these parts can be separated from each other, and thus made to escape microscopic observation; but still, where-
ever

ever water or its parts are seen, they are fluid.

As we are ignorant therefore of the nature of these parts separately, because we cannot separate them enough, we must be contented to enquire into those appearances which arise from their combination. Like all other bodies, we know they have weight, and therefore press downward by the force of gravity. A glass filled with water, is heavier than an empty one; a sponge floats while dry, but sinks when filled with water. We know also, that they yield to every pressure, for each of these minute parts being capable of making only a very small resistance, the combination of minute resistances will appear like one uniform resistance, opposing, yet giving way to every impression.

FROM this accumulation, and this resistance of the parts of any fluid, but particularly of water, many very striking

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appearances arise. Their different force, in pressing the bottom of a tall vessel and a shallow one; their supporting heavy bodies floating on their surface; their rising in one pipe to the same height from whence they descended, and thus ascending up the side of an hill, contrary to their natural weight; these and several other phenomena attract our curiosity, and demand explanation.

IN entering upon the first part of this theory, which shews how much the parts of fluids press upon the bottom and sides of vessels, or upon bodies which are plunged in them, we must be contented to begin with one property, verified by experience alone; we must start from an obvious appearance in all watery fluids, for which theory has been unable to account. The property of all waters is, that in a state of rest their surface is level.

Now then let us suppose three tubes or vessels united, and to have a communication

munication with each other; (fig. 36.) we know that if water be poured into the perpendicular vessel A, it will run into the horizontal vessel C, and rise in the other perpendicular vessel B, to the same level at which it stands in the vessel A.

FROM this obvious experiment we learn, that fluids press in all directions, upwards, sideways, downward, and in short, every way. For let us suppose that the tube B, were intirely taken away at *b*, it is evident that the water in the horizontal tube C, would still press against the part *b*, with as much force as it did before, whether the tube were there or not; and if the tube C were taken away, the water in A would press against the part *a*, with as much force as it did, whether C were there or not; water therefore presses the sides and bottom of the vessel that contains it in all directions. Thus far experience alone must be permitted to guide; and if we knew the figure of the parts of

A a 2

water,

water, we might be able to tell how they come to be endued with this property ; but as that is unknown to us, farther illustrations would only increase the obscurity.

AGAIN, suppose water were made to stand only at half the height d , in the tube A, it would then only rise to half the height e , in the tube B. The pressure therefore upwards at b , would then be but half as powerful as in the former case, when the water rose to B ; of consequence therefore, the pressure at a would be but half of what it was before ; and therefore the pressure of the water in the vessel A, upon its bottom, would be but half of what it was before. From hence we may in general conclude, that the pressure which water at any depth sustains will increase, as the height of the water above it increases. Thus, for instance, if the vessel be very high, the pressure at the bottom will be such as would make water rise to an equal height in
3 another

another vessel, and consequently it must be great.

FROM this last property we learn the cause why, if an hole opens in the bottom of a ship at sea, the water bursts through it with much greater violence than if an hole were broke in the ship's side, near what the mariners call the water's edge. In the first case, the water being greatly pressed by the weight of water over it having a free passage into the ship, presses in with a force, equal to the pressure itself sustains; on the other hand, the water in the latter case is not much pressed by the fluid above, as the hole is near the surface, and it therefore presses in with much less violence,

ALL this is incontestible; but the hydrostatic paradox we are now going to explain, will not be admitted so readily, though undoubtedly true. It is this: *The weight with which water presses upon the bottom of any vessel which holds*

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it, will be great in proportion to the height of the water in the vessel, and not to the quantity of water it contains. Thus, for instance, let there be two vessels A and B, both with their bottoms equally broad, and both equally high, but as we see of very different capacities; the bottom C of the smaller will be as much pressed by the water, as the bottom C of the larger, though one of them may contain but a few quarts, and the other as many hogheads.

WE will first prove this from theory, and then shew it true by experiment. Let us suppose two tubes *a b* inserted into the bottom of each vessel, the water will be pressed into both with such a force as will make it rise to a level with the rest of the water in both the vessels; but as the water is at equal heights in both vessels, the pressure up the tubes must be therefore equal. Now what is true of one tube, is equally true of a thousand, if they could all be inserted into
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the bottom; therefore, universally, the pressure of the water in each vessel upon every part of the bottom, and upon the whole bottom, must be equal.

IF two vessels of equal bottoms, but unequal capacities, as A and B, could have their bottoms so contrived as to fall out upon a certain degree of pressure; if, for instance, the bottoms were of brass covered with leather, to make them water tight, and capable of falling off when water was poured in to a certain height; it would be constantly seen that the brasses would fall when the water rose to a similar height, in either vessel.

ONE of the most useful machines to shew that a small quantity of water is capable of great pressure, is the hydrostatic bellows. This machine (fig. 37.) consists of two thick oval boards, each about sixteen inches broad, and eighteen inches long, united to each other by leather,

A a 4

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like a pair of common bellows, or a barber's puff. Into the lower board a pipe B, three feet high is fixed at e. Now, in shewing experiments with this simple machine, which even the reader himself might easily make, let water be poured into the pipe at its top c, which will run into the bellows, and separate the boards a little: then to shew how much a little water will be able to effect by pressure, let three weights, each of an hundred pounds, be laid upon the upper board. Now if we pour more water into the pipe, it will as before run into the bellows, and raise up the board with all the weights upon it. And though the water in the tube should weigh in all but a quarter of a pound, yet the pressure of this small force upon the water below in the bellows, shall support the weights, which are three hundred pounds; nor will they have weight enough to make them descend, and conquer the weight of the water, by forcing it out of the mouth of the pipe.

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IT is inconceivable what force a small quantity of water shall be made to exert, upon the bottom or sides of a vessel, when it stands in a high tube inserted into the vessel. A strong hoghead may by this means be split, and I have seen the experiment performed. Into the bunghole was inserted a strong, though small tube made of tin, and twenty feet high; when water was poured in through this, it filled the hoghead, and when it rose within about a foot of the top of the tube, the hoghead burst, and the water scattered about with incredible force.

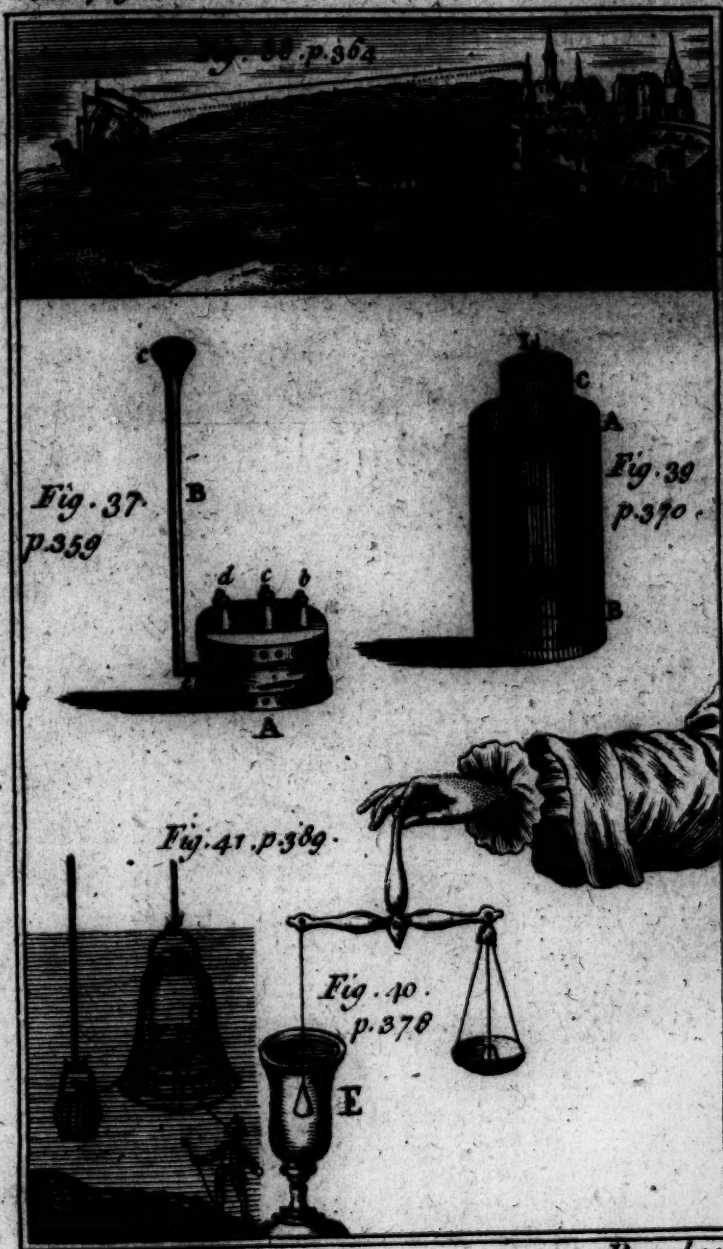
FROM hence we may see, that fluids will always rise to the same heights in pipes, from whence they descend. Thus, if there be a spring upon the brow of one mountain, and should it be required to conduct its waters across the valley, up the side of an opposite mountain; nothing more is necessary than to lay pipes of lead or hollowed timber along
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the surface of the ground, leading from the spring down one mountain side, along the valley, and rising up by the other; this will conduct the waters to any heights, which do not exceed the height of the spring from whence they are originally drawn. And the reason is obvious; all water will rise to its own level; we have seen it rise to the level, in the three small tubes A B C, and it would rise to the same, were these tubes each a mile in length, and equally high. But though in theory, water may be thus made to descend from the highest mountains, down the deepest vallies, and thus rise again on an opposite mountain's side, yet in practice this can scarcely be performed from any very great heights, because the pressure of the water is so very great in the pipes at the bottom of the valley, that no pipes can be contrived strong enough to endure it. We have seen how the pressure of twenty feet of water would burst a common hoghead; now if we should suppose the mountain
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four hundred feet high, we should find much difficulty to make any pipe strong enough to resist the water's weight at such an height. Pipes hollowed through rocks of marble, would in a short time burst, like those whose sides were of paper. For this reason, when the height is more than an hundred feet, engineers, instead of pipes, are obliged to raise aqueducts; these raising the water more to a level, the force against the sides of the tube is lessened, and it rises to the moderate height from whence it fell, without any injury to the pipe that conducts it. It is generally supposed, that this contrivance of carrying water down through vallies, and up against hills by pipes, was unknown among the ancients; but this is not the case, as could easily be shewn: they used aqueducts in their stead, because less subject to want repair, and furnishing water in greater abundance.

BEFORE I quit this chapter, one thing more may be mentioned relative to the surface

surface of waters. It was said that they were always level when at rest, but strictly speaking that is not the case: the earth is round, as we well know, and a great surface of waters therefore must be of the same shape, so that instead of being a large plane, they will partake, in some measure, of the earth's convexity. This convexity of the surface of waters, though scarcely discernable in minute bodies of water, is distinguishable enough at sea. Let us suppose the spectator upon shore, and a ship out at sea, (fig. 38.) the first part of the ship that will appear to the spectator's eye, will be the top masts, for the intervening convexity of the sea will prevent his seeing the lower part; just as if two men approached each other on opposite sides of an hill, their heads would be the first part that would be seen by each other, for the convexity of the hill would intercept the rest: as they would approach however they would see more, until they both stood totally visible upon the





the top. Just so it is with a spectator and a ship at sea: in every nine miles distance, there is about six feet of the earth's swell between us and any object; so that a man that stood in a boat at that distance at sea, would be totally unseen, though we took the best telescope to observe him withal. We cannot suppose however that this convexity, which is only visible at such distances, can be seen upon the bosom of a small lake or sheet of water; on the contrary, this may be regarded as perfectly plane, and all experiments are calculated upon that supposition.

C H A P. XXIII.

Of the Specific Gravity of Bodies.

WHEN an unspongy or solid body sinks in a vessel of water, it removes a body of water equal to its own bulk, out of the place to which it descends. If, for instance, a copper ball is let drop into a glass of water, we well know that if it sinks, it will take up as much room as a globe of water equal to itself in size took up before.

LET us suppose for a moment, that this watery globe removed by the ball were frozen into a solid substance, and weighed in a scale against the copper ball; now the copper ball being more in weight than the globe, it is evident that it will sink its own scale, and drive up the opposite, as all heavier bodies do when weighed against lighter; if, on the contrary, the copper ball be lighter than the water globe, the ball will rise.

Once

Once more then let us suppose the copper ball going to be immersed in water, and that in order to descend, it must displace a globe of water equal to itself in bulk. If the copper ball be heavier than the globe, its pressure will overcome the other's resistance, and it will sink to the bottom; but if the watery globe be heavier, its pressure upwards will be greater than that of the ball downward, and the ball will rise or swim. In a word, in proportion as the ball is heavier than the similar bulk of water, it will descend with greater force; in proportion as it is lighter, it will be raised more to the surface.

FROM all this we may deduce one general rule, which will measure the force with which any solid body tends to swim or sink in water; namely, *every body immersed in water, loses just as much of its weight as equals the weight of an equal bulk of water.* Thus, for instance, if the body be two ounces, and an equal

bulk of water be one ounce, the body when plunged will sink towards the bottom of the water with a weight of one ounce. If, on the contrary, the solid body be but one ounce, and the weight of an equal bulk of water be two ounces, the solid when plunged will remove but one ounce, that is, half as much water as is equal to its own bulk, so that consequently it cannot descend; for to do that, it must remove a quantity of water equal to its own bulk. Again, if the solid be two ounces, and the equal bulk of water two ounces, the solid, wherever it is plunged, will neither rise nor sink, but remain suspended at any depth.

THUS we see the reason why some bodies swim in water, and others sink. Bodies of large bulk and little weight, like cork or feathers, must necessarily swim, because an equal bulk of water is heavier than they; bodies of little bulk but great weight, like lead or gold, must sink, because they are heavier than an
equal

equal bulk of water. The bulk and the weight of any body considered together, is called its specific gravity, and the proportion of both in any body, is easily found by water. A body of little bulk and great weight, readily sinks in water, and it is said to have great specific gravity; a body of great bulk and little weight, loses almost all its weight in water, and therefore is said to have but little specific gravity. A woolpack has actually greater real gravity, or weighs more in air than a cannon ball; but for all that, a cannon ball may have more specific gravity, and weigh more than the woolpack in water. Density is a general term that means the same thing; specific gravity is only a relative term, used when solids are weighed in fluids, or fluids in fluids.

BUT before we proceed in this theory, it may not be amiss to get over an objection that will naturally arise. It may be said, that as in the descent of heavy bodies in fluids, the deeper they descend, the more they must be resisted;

how comes it that by the time they get towards the bottom, they are not totally stopt from descending, and driven by the increased resistance upward? The answer is easy; the lower surface of the descending body is prest with encreased resistance upwards, it is true; but at the same time the upper surface is pressed with increased resistance downward. These two increased and opposite forces balance each other, and make no difference in the descent.

If however a method were contrived, while the heavy body was descending, to take away the pressure from above, and leave that below all its increasing force, then indeed the increased pressure from below, would actually prevail over the body's superior weight, and drive it upward; so that by this means, lead or gold itself might be made to swim upon water. The experiment has been conducted in the following manner. A glass tube CD, (fig. 39.) open at both ends, was fitted with a leaden bottom half

half an inch thick, which was held close to the tube by pulling a string fixed in its middle, up through the tube, as so the bottom could not thus fall off. In this manner the tube was immersed in water, in the glass vessel A B, to the depth of three inches only below the surface of the water at K, by which means the leaden bottom was plunged somewhat more than to eleven times its own thickness. At that depth the bottom, which had no pressure of water above it, and had a strong pressure below, would not sink nor fall from the tube, but actually swam at that depth upon the water. If however, a pressure above were made, by pouring a little water into the tube, then the lead would sink with its usual velocity.

IN the same manner as an heavy body was made to swim on water, by taking away the upward pressure, so may a light body like wood, be made to remain sunk at the bottom, by depriving it of all

B b 2

pressure

pressure from below; for if two equal pieces of wood be planed, surface to surface, so that no water can get between them, and then one of them be cemented to the inside of the vessel's bottom, then the other being placed upon this, and while the vessel is filling, being kept down by a stick, when the stick is removed and the vessel full, the upper piece of wood will not rise from the lower one, but continue sunk under water, though it is actually much lighter than water; for as there is no resistance to its under surface to drive it upward, while its upper surface is strongly pressed down, it must necessarily remain at the bottom. The following method of making an extremely heavy body float upon water, is more elegant than the former. Take a long glass tube, open at both ends, stopping the lower end with a finger, pour in some quicksilver at the other end, so as to take up about half an inch in the tube below. Immerse this tube, with the finger still at the bottom,

bottom, in a deep glass vessel filled with water; and when the lower end of the tube is about seven inches below the surface, take away the finger from it, and then you will see the quicksilver not sink into the vessel, but remain suspended upon the tube, and floating, if I may so express it, upon the water in the glass vessel,

As every solid sinks more readily in water, in proportion as its specific gravity is great, or as it contains greater weight under a smaller bulk, it will follow, that the same body may very often have different specific gravities, and that it will sink at one time, and swim at another. Thus a man, when he happens to fall alive into the water, sinks to the bottom; for the specific gravity of his body, is then greater than that of water: but if by being drowned he lies at the bottom for some days, his body swells by putrefaction, which disunites its parts; thus its specific gravity becomes

less than that of water, and he floats upon the surface.

THERE is a pretty childish contrivance by which the specific gravity of the body is so altered, that it rises and sinks in water at our pleasure. Let little images of men, about an inch high, of coloured glass, be bespoke at a glass-house, and let them be made so as to be hollow within, but so as to have a small opening into this hollow, either at the sole of the foot or elsewhere. Let them be set afloat in a clear glass phial of water, filled within about an inch of the mouth of the bottle; then let the bottle have its mouth closed with a bladder, closely tied round its neck, so as to let no air escape one way or the other. The images themselves are nearly of the same specific gravity with water, or rather a little more light, and consequently float near the surface. Now when we press down the bladder, tied on at the top, into the mouth of the bottle, and thus press the
air

air upon the surface of the water in the bottle; the water being pressed will force into the hollow of the image through the little opening; thus the air within the image will be pressed more closely together, and being also more filled with water now than before, the image will become more heavy, and will consequently descend to the bottom; but upon taking off the pressure from above, the air within them will again drive out the water, and they will rise to the same heights as before. If the cavities in some of the images be greater than those in others, they will rise and fall differently, which makes the experiment more amusing.

THIS is but an experiment of mere amusement; much more important uses are the result of our being able exactly to determine the specific gravities of bodies. We can, by weighing metals in water, discover their adulterations or mixtures, with greater exactness than by

any other means whatsoever. By this means the counterfeit coin, which may be offered us as gold, will be very easily distinguished, and known to be a baser metal. For instance, if I am offered a brass counter for a guinea, and I suspect it; suppose, to clear my suspicions, I weigh it in the usual manner against a real guinea in the opposite scale, and it is of the exact weight, yet still I suspect it; What is to be done? To melt or destroy the figure of the coin would be inconvenient and improper: a much better and more accurate method remains. I have only to weigh a real guinea in water, and I shall thus find that it loses but a nineteenth part of its weight in the balance; I then weigh the brass counter in water, and I actually find it loses an eighth part of its weight, by being weighed in this manner. This at once convinces me that the coin is made of a base metal, and not gold; for as gold is the heaviest of all metals, it will lose less of its weight by being weighed in water than any other.

THIS

THIS method *Archimedes* first made use of, to detect a fraud with regard to the crown of *Hiero*, king of *Syracuse*. *Hiero* had employed a goldsmith to make him a crown, and furnished him with a certain weight of gold for that purpose; the crown was made, the weight was the same as before, but still the king suspected that there was an adulteration in the metal. *Archimedes* was applied to, who, as the story goes, was at first unable to detect the imposition, but the resistance he found from the water, in going into a bath, gave him the hint of weighing the crown hydrostatically. A mass of pure gold was procured, which weighed equal with the crown in air; but when both were weighed in water, the crown proved much the lighter of the two, a positive proof that the metal, of which it was composed, was not so heavy as pure gold.

UPON this difference in the weight of bodies in open air and water, the hydrostatic

static balance has been formed, which differs very little from a common balance, but that it hath an hook at the bottom of one scale, on which the weight I want to try may be hung by an horse hair, and thus suspended in water, without wetting the scale from whence it hangs. First, the weight of the body I want to try, is balanced against the parcel or weight E, in open air; (fig. 40.) then the body is suspended by the hook and horse hair at the bottom of the scale, in water, which we well know will make it lighter, and destroy the balance. We then can know how much lighter it will be, by the quantity of the weights we take from the scale E, to make it equipoise; and of consequence, we thus precisely can find out its specific gravity compared to water. There are several different ways in which the hydrostatic balance is constructed; if the scales be very nice, it matters little as to the rest.

THIS

THIS is the most exact and infallible method of knowing the genuineness of metals, and the different mixtures with which they may be adulterated, and it will answer for all such bodies as can be weighed in water. As for those things that cannot be thus weighed, such as quicksilver, small sparks of diamond, and such like, as they cannot be suspended by an horse-hair, they must be put into a glass bucket, the weight of which is already known; this, with the quicksilver, must be balanced by weights in the opposite scale as before, then immersed, and the quantity of weights to be taken from the opposite scale, will shew the specific gravity of the bucket and the quicksilver together; the specific gravity of the bucket is already known, and of consequence the specific gravity of the quicksilver, or any other similar substance, will be what remains.

As we can thus discover the specific gravity of different solids, by plunging them

them in the same fluid, so we can discover the specific gravity of different fluids, by plunging the same solid body into them; for in proportion as the fluid is light, so much will it diminish the weight of the body weighed in it. Thus we may know that spirit of wine has less specific gravity than water, because a solid that will swim in water, will sink in spirit; on the contrary, we may know that spirit of nitre has greater specific gravity than water, because a solid that will sink in water, will swim upon the spirit of nitre. Upon this principle is made that simple instrument, called an Hydrometer, which serves to measure the lightness or weight of different fluids. It is nothing more than an hollow copper ball, with a short stalk or stem fitted into, or if I may so express it, growing out of the ball; this ball is so made, as partly to sink but not entirely in water, and so poised that the stem shall always stand upright: the lower it sinks, the lighter the fluid; and on the
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contrary, the higher it swims, the more heavy the fluid thus supporting it. How much it sinks or swims may be very exactly known by the stalk, which is graduated or marked; and this instrument is often used by those, whose business is to examine the different densities of liquors, such as drunkards, inn-keepers, distillers, and excisemen.

THIS instrument, I say, will serve to measure the specific gravities of different liquors, for it is found by experience, that liquors weigh very differently from each other; an experiment or two to shew this will suffice. Suppose we take a glass vessel which is divided into two parts, communicating with each other by a small opening of a line and an half diameter. Let the lower part be filled up to the division with red wine, then let the upper part be filled with water. As the red wine is lighter than water, we shall see it in a short time rising like a small thread up through the water, and diffusing

diffusing itself upon the surface, till at length we shall find the wine and water have changed their places; the water will be seen in the lower half, and the wine in the upper half of the vessel.

IN the same manner we may pour four different liquors, of different weights, into any glass vessel, and they shall all stand separate and unmixed with each other. Thus, I take mercury, oil of tartar, spirit of wine, and spirit of turpentine, shake them together in a glass, let them settle a few minutes, and each shall stand in its proper place, mercury at the bottom, oil of tartar next, spirit of wine, and then spirit of turpentine above all. Thus we see liquors are of very different densities, and this difference it is that the hydrometer is adapted to compare. In general, all vinous spirits are lighter than water, and the less they contain of water, the more light they are. The hydrometer therefore will inform us how far they
are

are genuine, by shewing us their lightness; for in pure spirit of wine it sinks less than in that which is mixed with a small quantity of water.

YET after all, we are not entirely to depend, and with geometrical certainty rely upon either the hydrometer or the hydrostatic balance, for there are some natural inconveniences that disturb the exactness, with which they discover the specific gravities of different bodies. Thus, if the weather be hotter at one time than another, all fluids will swell, and consequently they will be lighter than when the weather is cold; the air itself is at one time heavier than at another, and will buoy up bodies weighed in it; they will therefore appear lighter, and will of consequence seem heavier in water. In short, there are many causes that would prevent us from making tables of the specific gravities of bodies, if rigorous exactness were only expected, for the individuals of every kind of
sub-

substance differ from each other, gold from gold, and water from water. In such tables therefore, all that is expected is to come as near the exact weight as we can, and from an inspection into several, we may make an average near the truth. Thus, *Muschenbrook's* table makes the specific gravity of rain water, to be nearly eighteen times and an half less than that of a guinea; whereas our *English* tables make it to be but seventeen times and an half nearly less than the same. But though there may be some minute variation in all our tables, yet they in general may serve to conduct us with sufficient accuracy.

IN general it may be observed, that the purest gold is the heaviest of all other substances whatsoever, being nearly nineteen times and an half heavier than water; next to gold, is a semi-metal of late discovered, called Platina; this, if I remember right, is sixteen times one third heavier than water; mercury is
next

next in weight, and is a little more than fourteen times heavier than water; lead, eleven and about a quarter; fine silver, about eleven only; copper, is eight and three parts; steel, seven and three parts; and thus of the rest; diamond is about three times and an half heavier than water; glass, about three and a quarter; rectified spirit of wine, is about one third lighter than water, and cork is more than four times as light.

Now then, suppose a body to be a mixture of gold and silver, and it is desired to know the quantities it contains of each; I first find, by the hydrostatic balance, the specific gravity of the compound. We know that its specific gravity is less than that of gold, but more than that of silver; let us subtract then the known specific gravity of silver, which we said was eleven, from the specific gravity of the compound, and let us subtract the compound itself from that of gold, which is nineteen;

the first remainder shews the bulk of the gold in the compound, the other that of the silver: and as we know the bulk of each, and the specific gravities of each, we may easily know their real weights or gravity, by multiplying the bulks by the specific gravities.

ALL exprest oils, such as olive oil, rape oil, and the like, which are pressed out of kernels or seeds by means of heat, these and all fatty suety substances, are about a tenth part lighter than water, and therefore swim upon its surface. From hence it is easy to conceive the reason, why animals that are fat swim better than those that are lean, since the former contains a quantity of oil within their surface, which is specifically lighter than water, and consequently keeps them buoyant. Thus the country people assure us, that a fat hog swims better than any other animal; and they have reason for their assertion.

OF all animals thrown into water, man is the most helpless. The brute creation receive the art of swimming from nature, while man can acquire it only by practice; the one escapes without danger, the other sinks to the bottom. Some have asserted, that this arises from the different sensibilities each have of danger: the brute, unapprehensive of danger, and unterrified at its situation, struggles through, while his very fears sink the lord of the creation. But much better reasons may be assigned for this impotency of man in water, when compared to other animals; and one is, that he has actually more specific gravity, or contains more matter within the same surface, than any other animal whatsoever. The trunk of the body in other animals is large, and their extremities proportionably small; in man it is the reverse, his extremities are very large, in proportion to his trunk: the specific weight of the extremities is proportionably greater than that of the trunk in

all animals, and therefore man must have the greatest weight in water, since his extremities are largest. Add to this, that in order to swim, other animals have only to walk forward, if I may so express it, upon the water; the motion they give their limbs in swimming, is exactly the same with that they use upon land: but it is different with man, who makes use of those limbs to help his motion upon water, which, upon land, he employs to very different purposes.

As we have observed above, that liquors of different densities support bodies in proportion to their density; that the heavier the liquor, the heavier will be the weight it can support; it is not to be wondered at, that in swimming, we should find ourselves much better buoyed up and supported in sea-water than in fresh. For sea-water is actually heavier, and this from the salts mixed with it which increase its weight about a fiftieth part.

IN order to facilitate our power of remaining on the surface of water, or of breathing when at the bottom, different methods have been contrived. As to the first, the cork waistcoat answers the purpose tolerably well; for the latter, the diving bell is a well known security. Doctor *Halley*, in a diving bell of his own contrivance, remained fifty two feet deep at the bottom of the sea, for the space of an hour and an half.

THE diving bell is an instrument long known and in use. That made by Doctor *Halley*, was in the form of a great bell, and was coated with lead, so as to make it sink in water: (fig. 41.) it was three feet wide at top, five feet wide at bottom, and eight feet high. Into this great bell the diver entered, and sat upon a small seat within-side, prepared for that purpose, and received light from a strong glass at top. Thus prepared, by means of a rope, the bell, the man and all was let down to the

bottom, in order to search for goods, or fix cords to wrecks of ships, and such like purposes.

WHEN the bell is let down into the sea, the water rises into it to a certain height, but it cannot fill the whole of the bell, for the air within it (as we shall see hereafter) will still keep some room at top, and prevent the water's rising and filling it any farther. It is in this topmost part, which is empty or only filled with air, that the diver keeps his head, and breathes that air which thus resists the ascending water; here he can remain for some time, living upon the condensed air, and at the same time performing what he descended for.

BUT to be more particular in the description of Doctor *Halley's* bell. In the top was fixed, as mentioned above, a strong clear glass to let in the light from above, and likewise a cock to let

let out the hot air, that had been polluted by repeated inspiration below. It was suspended from the mast of a ship, and so hoisted over the ship's side as to be let down without danger. In this, two or more divers were let down to the bottom, and two barrels of air were let down to them, to supply them with fresh air, which alternately rose and fell like two buckets. As the air from the barrels was let into the space in the bell free from water, it entered cold, and expelled the hot air which had been spoiled, out through the cock at the top. By this method air was communicated in such plenty, that the Doctor informs us, that he was one of five who were together at the bottom in ten fathom of water, for above an hour and an half at a time, without any sort of ill consequence; and he might have continued there as long as he pleased, for any thing that appeared to the contrary. By the glass at the top of the bell, so much light was transmitted when the sun

stone, and the sea undisturbed, that he could see perfectly well to read and write, or to find any thing that lay at the bottom; but in dark weather, and when the sea was rough, he found it as dark as night at the bottom. But then this inconvenience might be remedied, by keeping a candle burning in the bell as long as he pleased; for he found by experience, that a candle polluted the air by burning, just as a man would by respiring, both requiring about the same quantity of fresh air for their support, to the amount of nearly a gallon in a minute.

THIS machine was so far improved, that one of the divers might be detached to the distance of eighty or an hundred yards, by a close cap being put upon his head, with a glass in the fore part for him to see through, and a pipe to supply him with air, communicating with the great bell; this pipe was flexible, coiled round his arm, and served

served him as a clue to find his way back to the bell again. The only inconvenience that *Halley* complained of was, that upon their first descending, his companions and he found a small pain in their ears, as if the end of a quill were thrust forcibly through into the aperture of the ear. One of the divers however, willing to remedy this inconvenience, stuffed his ears with chewed paper, which, as the bell descended, was so forcibly pressed into the cavities of the organ, that the surgeon could not extract the stuffing without great difficulty.

Triedwald, a *Swedish* engineer, has made some improvements on this machine, since *Halley's* time. That contrived by him is less than *Halley's*, and consequently more easily managed; it is illuminated with three convex glasses instead of one. It has been found, that the nearer the diver's head is to the surface of the water in the bell, the better

better he breathes, for the air at that place is most comfortable and cool. In *Triedwald's* bell, the diver's head is therefore nearer the water, and when there is a necessity for his lifting up his head to the top of the bell, he has a flexible pipe in his mouth, with which he breathes only the air at the surface of the water at the bottom of the bell.

WE are told of a much more useful method than either of the former, put in practice by a gentleman of *Devonshire*. He has contrived a large case of strong leather, perfectly water proof, which may hold about half an hoghead of air. This is so contrived, that when he shuts himself up in this case, he may walk at the bottom of the sea, and go into any part of a wrecked vessel, and deliver out the goods. This method, we are told, he has practised for many years, and has thus acquired a large fortune.

IN this manner we find, that no part of nature is wholly secluded from human
vifi-

visitation, since thus means have been contrived, to descend without danger to the bottom of the ocean, and to explore that abyfs which seems, at first view, to retire from curiosity. Without the contrivance above mentioned, men, when at such vast depths below the surface of the water, would feel the effects of its weight in a very sensible manner. Divers who go to the bottom without this machinery, often return with signs of the violent pressure of the water upon the surface of their bodies; their eyes are seen swollen and blood-shot, they often bleed at the mouth and nose, and feel a total lassitude over their whole bodies. These symptoms are most violent, in such as first undertake this kind of employment; but they lessen by degrees, so that an accustomed diver feels no great inconvenience, by remaining some minutes at the bottom: those of this profession, are only remarkable for the redness of the white of their eyes.

BEFORE

BEFORE I quit this subject, it may not be improper to mention a benefit that may accrue, from plunging or bathing in sea water, not yet that I know taken notice of by others. Many arts have been tried to make sea water fresh and potable; the benefit of which would be, that in long voyages, when a ship's company wanted fresh water, they might make use of sea water as a very easy substitute, by freshening it according to art. The best method of freshening salt water is, by mixing it with calcined bones, and then distilling it; for it is found that the calcined bones will lay hold on the saline parts of the water, unite with them, and keep them at the bottom of the still; while on the other hand, the fresh fluid will rise in vapours to the top, and thus separate from the impure mixture below. There is but one objection that I know of, to these calcined bones and this still, and that is, that they take up almost as much room in the ship, as so much fresh water as they

they could make would do. If the Captain of a vessel therefore, is apprehensive that they may want water in his voyage, instead of so many hundred weight of calcined bones, he may take so many supernumerary hogsheds of fresh water, and that will do as well. Common water will be almost as conveniently carried, much more wholesome, and infinitely cheaper; for this reason we never see captains of ships carry out calcined bones to sea; for if danger is foreseen, they supply themselves with superfluous stores of water. In unexpected calamities, perhaps the following method would for some time preserve life without fresh water.

If we are weighed upon going into a warm bath, we shall find upon our returning out of it, that we have gained considerably from the fluid in which we have been plunged, being often increased in weight some pounds; the reason is, that there are numerous
vessels

vessels opening at the pores of the skin, that suck up the water like so many capillary tubes, and these vessels run from every part of the surface of the body into the intestines, and discharge themselves there. These very fine slender vessels are a modern discovery, and still contested by different anatomists, each claiming the first observation of them to himself. We find also by experience, that though we be never so thirsty upon entering a warm bath, the bath instantly relieves that complaint, and we feel drought no more. What then, if in cases of extremity at sea, a warm bath of sea water were made, in which each of the ship's company might bathe, and thus, by the pores of the skin, drink in a sufficient quantity of watery fluid to sustain nature, and to dilute their other aliments? We know by experience that they would thus imbibe fresh water alone, for the pores of the skin are too minute to let the saline parts of water enter. The body, when plunged in a
I bath

bath of salt water, acts like a filter upon the fluid, and its pores suffer nothing but the thinnest and purest part to enter them; while the salt stands like hoar frost upon the surface of the skin, and may be wiped away with a towel. I do not care to drive an hint of this nature farther than it should go; nor is it to be wished that the assistance this may afford, should induce men to be less assiduous in providing the more adequate means of security.

C H A P. XXIV.

Hydraulics.

HYDROSTATICKS, as we have seen, determines the weight or pressure of fluids upon solids, or upon each other, in vessels where the water is not suffered to escape but remain at rest; hydraulics is a different part of this science, which teaches us to estimate the swiftness or the force of fluids in motion.

It has been always thought an enquiry of great curiosity, and still greater advantage, to know the causes by which water spouts from vessels to different heights and distances. We have observed, for instance, an open vessel of liquor upon its stand, pierced at the bottom; the liquor, when the opening is first made, spouts out with great force, but as it continues to run, becomes less violent, and the liquor flows more feebly;
a know-

A knowledge of hydraulics will instruct us in the cause of this diminution of its strength; it will shew precisely how far the liquor will spout from any vessel, and how fast, or in what quantities it will flow. Upon the principle of this science, many machines worked by water are entirely constructed; several different engines used in the mechanic arts; various kinds of mills, pumps and fountains are the result of this theory, judiciously applied.

AND what is thus demonstrated of the bottom of the vessel, is equally true at every other depth whatsoever. Let us then reduce this into a theorem. *The velocity with which water spouts out at an hole in the bottom or side of any vessel whatsoever, is in proportion to the square root of the height of the water in the vessel:* that is, in other words, If the water in one vessel be nine times higher than in another, it will spout with three times as much velocity; if the vessel be

four times as high as the water, it will spout with twice the velocity. We need scarce observe that the quantity of water spouted, is always equal to the velocity with which it spouts; so that a vessel nine times as high as another, will spout through a similar hole three times as much water, in the same space of time, or a vessel four times higher, will spout twice as much water. As an experimental proof of this, we may take two vessels, one five inches high, the other four times that height, and make a circular orifice in the bottom of each, of the sixth part of an inch diameter, and being both filled with water let them be set a running, and let the water be supplied above as fast as it runs out below; the taller vessel will discharge about two pounds of water avoirdupoise, in the space of a quarter of a minute; the vessel four times as short, will discharge just half that quantity.

As the pressure the bottom sustains, is sustained also by the sides of a vessel

vessel in proportion to their height, water will flow from the side of a vessel with the same force that it does downward; for it is found to flow out of both with the same velocity, provided they are at equal depths below the surface; and therefore the velocity of water flowing out at an orifice in the side of a vessel, is in the same proportion as before, that is, as the square root of the height of the water above the orifice, which a repetition of the former experiment may prove, by using vessels with orifices at the sides.

Now as we are thus informed of the velocity with which water flows through an hole in the side of a vessel, it may be requisite to know to what distance it will thus spout sideways. To know this, let us suppose the water spouting from the side of a vessel, to move uniformly forward, with the velocity it has received, which is as the square root of the height of the vessel;

now this velocity would drive it uniformly forward, through a space equal to twice the height of the vessel; for we shewed formerly, that a body having acquired a certain velocity by falling, would, if it moved uniformly forward with that velocity, go through double the space from whence it fell; and this is the case with the spout of water, which if nothing prevented would always spout forward to double the distance of the height it stands in the vessel.

BUT now we know that gravity acts upon it, and draws it downward, so that the spout is impressed by two forces that influence it, one forward, the other downward; these motions by no means destroy each other, the spout obeys both, and like all projected bodies it moves in the curve of a parabola. Let us then suppose the water is let flow through an hole in the vessel B, at its top b; as it has no height of water there above it, it will not spout at all, but drivel down the
side

side of the vessel : let us, on the contrary, suppose it to be let flow through an hole c, just near the bottom on the ground; now strictly speaking, it will not spout there neither, for as the spout is always descending by its gravity, it will meet the ground the moment it leaves the orifice, and thus have no spout at all. Thus at b, the water had no spout for want of height to drive it; at c, the water hath no spout for want of room to descend; it will therefore have the greatest spout at the greatest distance from these two destroying extremes, and at a, it will go forward, as we said before, to twice as far as the water is high above it; and at all other heights or depths of the vessel the water will spout in a similar proportion, and from all holes equally distant above and below the middle, the jets of water will be made to similar horizontal distances. I would only observe here, that the usual method by which some determine the distance to which water will spout by a semi-circle, &c. is erroneous.

THUS we may universally conclude, that water spouts to double the distance of its height, provided it is raised above the level of the ground so as to take its full range. But though this is true in theory, yet we find in practice that there are great deviations from all the rules preceding; for we must now observe, that the water does not spout in a compact parallel stream from an hole in the vessel's side; for *Newton* has justly observed, that the diameter of the spout is largest immediately issuing from the hole, that then it contracts its diameter as it proceeds a little way, and lastly, it scatters about in all directions; so that we may compare the spout to a cone, the base of which is at the mouth of the hole, and the point at some distance from it. It is not the diameter of the hole therefore that should be measured, to know the quantity of water that pours out in a certain time, but the diameter of this point or vein, at a little distance from the hole; and the admeasurement of this

Bernouilli

Bernouilli has actually attempted, but with what success I will not pretend to determine; it may only be observed, that the cause of this convergence in the spout is still in dispute among the learned: the argument, from its intricacy, it is probable, will not be easily adjusted; however, let us not enlarge upon so minute an enquiry, when there are so many greater to engage our attention.

To remedy this scattering of the fluid as it issues from the hole, we all know of the contrivance of the fossier or ajutage, which is only a pipe stuck into the hole, that serves to give the fluid a proper direction; this, while it answers the end proposed, at the same time diminishes both the velocity of the spouting fluid, and the distance to which it would go. The length of the ajutage may be considered as a column of water of an equal height, resisting the force of the fluid that spouts through it; so

that if the ajutage be as long as the spouting water is high, the two opposite forces will thus destroy each other, and there will be no spout to any distance whatever.

THUS far as to water spouting horizontally, or as we usually say sideways from a vessel; now as to its spouting directly upward, water will spout upward with such a velocity as will carry it to the same height with the water in the vessel from whence it spouts, because the velocity it has at the bottom, is equal to the velocity it would acquire in falling down from the top of the water; and this velocity has force enough to carry it an equal space upward, as we formerly explained. The water therefore will spout in all fountains to nearly an equal height with the water in the vessels from whence it flows; I say nearly, because, as we know, the air will give it some resistance, and must lessen the force of all jets whatsoever, and
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make them fall short of the height of the water in the reservoirs. But there is another cause that diminishes the height of the water's play; for when the water at the top of the spout has lost all its motion, it rests for some time on the part below, and by its weight obstructs the motion of a new column issuing from below, and thus prevents it from rising. The resistance arising from this cause is so great, that the jet is frequently destroyed by it; the rising water being by fits and starts pressed down to the very orifice from which it spouts. But this inconvenience is remedied if we give the jet a little inclination, for then the uppermost parts, when they have lost all their motion upward, do not fall back as before, but are made to fall off from the rest, and thus do not incumber the rising fluid. From hence therefore we may understand the reason, why such jets as are a little inclined, rise higher than those, whose ascents are perpendicular.

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IT is the difference in the figure of the ajutage, that gives a diversity of play to the fountain, and nothing can be more pleasing to the eye than the different manner in which water is made to spirt in these machines. But they give additional pleasure in sultry climates, such as *Italy*, where they contribute to cool the air as well as to enliven the prospect: with us they are chiefly made for the purposes of embellishment alone, for in our northern climate, the air is seldom disagreeable from too much warmth, and if there were fountains of fire, they would often make the most grateful ornament. I only mean this as an hint, concerning the unnecessary expence which many are at to procure fountains, in a country where the climate calls for different modes of embellishment. Our groves and our fields are greener than in any other region in the world; to improve the beauty of these, our artists should bend their chief efforts, and in this they will find nature conspiring with their industry.

WE have hitherto spoke only of the flowing of water from vessels and reservoirs that are open; we must now observe, that from vessels closely shut it will not spout at all. We all very well know that the liquor will not run from a close cask, unless the air is let in from above; for this purpose, when a hog-head of liquor is broached, there is always a vent hole made at top, which is occasionally opened when we want to draw liquor through the fossét or ajutage below. The cause why a fluid will not run from a close cask without the admission of air, shall be explained more largely when the properties of air come to be examined. Let it suffice to observe here, that the air presses with great force upon that part of the surface of every fluid to which it has admission. If an hole is opened in the side of a cask that is quite full of liquor, the air presses upon that hole with great violence, and prevents the liquor from coming out; if now another hole be opened at the top of
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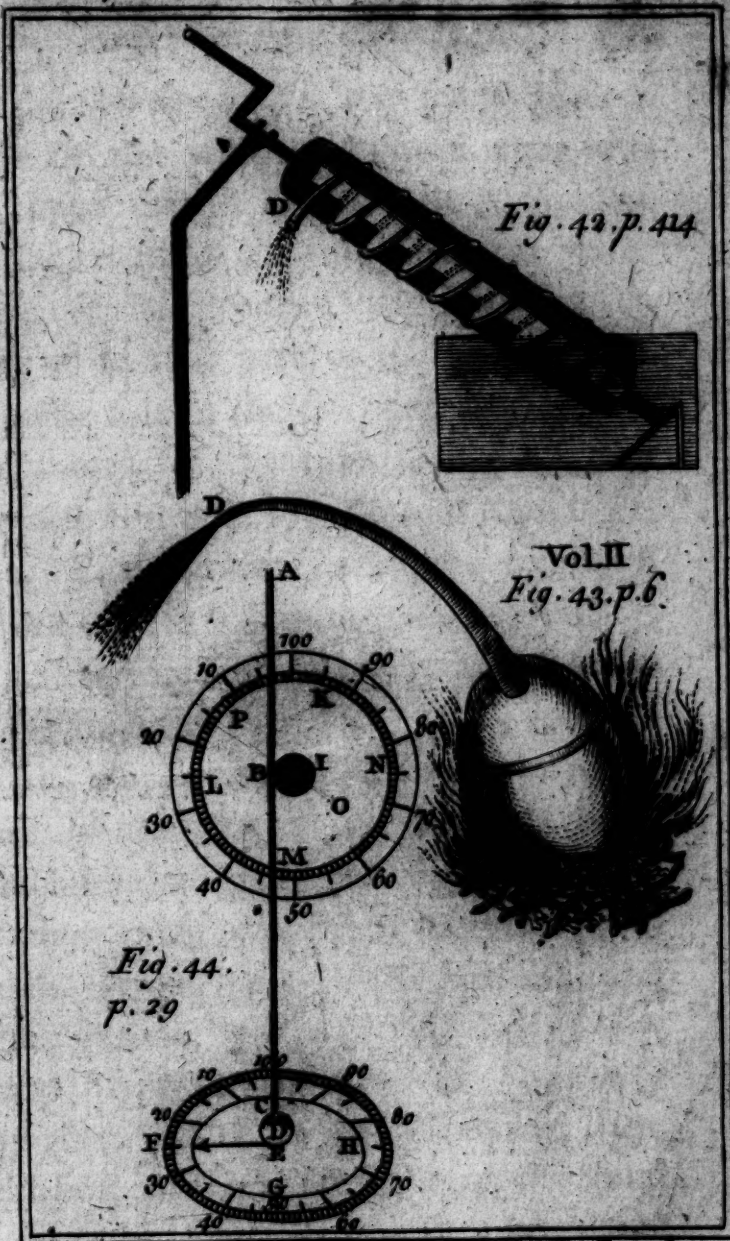
the cask, the air will press into this also with equal force, and press the liquor out: these two forces balance each other, so that the weight of the fluid, if I may so say, turns the scale, and it flows out. In general however, as our casks are not filled quite full, there is a little air left at the top of the vessel; immediately therefore, when the side of the cask is pierced, this air presses down, and there is a spirt of the liquor, but as the liquor continues to flow it leaves more room at the top of the cask; and the air not being capable of filling this room as before, presses with less force down, than the external air presses at the mouth of the orifice up; so that the fluid will no longer continue to flow, until more air is let in by a vent-hole at top, to balance that which presses against the egress of the liquor at the hole below,

FROM hence we see the necessity of having a vent hole, or some contrivance of this kind, in all casks that have liquors upon

upon draught; and from hence also we may deduce a reason why liquors, that have been long upon draught, grow vapid or sour; for the spirits being lightest always float and mix with the air at the top of the cask, and every time the vent-hole is opened, we may perceive them fly out with some violence. Thus by frequently opening the vent-hole almost all the spirit evaporates away at last, and leaves the liquor either vapid or sour. If this be true, might not a contrivance be made that would give a sufficient pressure to the upper surface of the fluid, without permitting the spirit to evaporate? What if a small tube were contrived, with a valve, which being inserted at the top of the cask, we might force in as much air as we thought proper into the cask above, while at the same time none of the air or spirit in the cask, would be permitted to come back through it or escape; this would at once give a sufficient force to make the liquor flow, and would also confine
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the spirit from evaporation. Whether this method has been already practised I know not; it is here only offered as a conjecture, *Valeat quantum valere potest.*

As to the description of several hydraulic machines, such as the pump, the syphon, the fire engine, and the intermitting fountain, we shall reserve these till we treat of air, which contributes so much to their operations. Among the number of hydraulic machines we must not omit to mention the screw of *Archimedes*, which raises water to small heights, and is at once the most simple and admirable of all the hydraulic machines. It consists of a long round beam or cylinder, (fig. 42.) with an hollow pipe coiled round it like a corkscrew, and open at each end. This machine is fixed slanting with one end in the water, and the other supported in such a manner upon a prop, that turns by means of an handle, as we sometimes see a spit turned in the country. As soon





as the lower end of the screw gives a turn in the water, the fluid runs into the open mouth of the tube at A, and as the mouth of the tube rises, the water which it has scooped up, sinks by its weight to that part of the tube on the opposite side of the cylinder, so that now the mouth of the tube is highest, and the water in it is lowest, and cannot get out. In the mean time, as the mouth of the tube is still in the water, while it is descending, the water it had scooped in before cannot get back again, because it has not force to overcome the resistance of the rest of the external fluid, which presses against it as forcefully as its contents press out; when it comes therefore a second time to the bottom, and again begins to rise, it will take a new scoop of water, and the water it already contained being in its descending state, will sink into the lower part of the spiral that is next to it, so that it is prevented from returning by the pressure behind, and still falls, if I may so say, forward
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by its own gravity, till it flows out at the top of the screw D.

THE human frame as well as that of all other animals, is usually represented as a most compound hydraulic machine, with an infinite number of tubes, conveying their respective fluids from one part of the body to the other. In this system of vessels philosophers have supposed the various kinds indued with various powers; they have fancied some acting as pumps, others as capillary tubes, nor has there been wanting such as have made mention of the glandular screw. The most distant resemblance between the vessels of the human body and these artificial machines, have given men, whose imaginations were strong, frequent opportunities of completing the picture. This, in common conversation, is called ingenious error; yet surely false philosophy can have no ingenuity whatsoever: for what is it that can make its rigid institutions pleasing, but that

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we suppose them true. Philosophy, that attempts to rectify the mind, is its physic, not its food; and it is but a small honour to that physician of whom it is said, that his pills are sweet but inefficacious.

IN this manner attempts have been made to determine the velocity with which the blood circulates through the body. Some of these speculators have not even taken into consideration the flexibility of the canal, through which the animal fluids move, but have given us hydraulic theories, drawn from the spouting of fluids through glass pipes. Nothing can be more erroneous than this, but if it were only a speculative error it would be scarce worth combating; nothing can be more dangerous too; and in fact, very dreadful practice has been recommended, in consequence of these ill guided calculations. But though we should suppose that even the whole theory of fluids spouting through flexi-

ble and elastic tubes were known, (and it is not till of late that an ingenious modern has attempted the investigation) yet we should be still as far from understanding the velocity of the circulating fluids of the human body as before. To treat this with any precision, we must first know exactly to what degree a vein or an artery is capable of dilating, we must know the figure of the vessels, their elasticity, their different openings into each other, the force and the disposition of their valves, the degree of heat and tenacity of each fluid, and the force which drives them forward. If all these were known, where would the mathematician be found, that could unite such various elements into one calculation? Even to determine the force of fluids in flexible tubes, alone, almost exceeds geometrical strength; what then must be the case in such a complication of component parts? Modern phyfic has with great justice exploded those idle and dangerous algebraic dreams, conceived

ceived in an age when geometry walked from her circle to conduct mankind to error, and was seen daily applying her compass to the incommensurable parts of nature,

END OF THE FIRST VOLUME.



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